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Reducing emissions in the Mexican power sector: Economic and political feasibility analysis of policy mechanisms

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Abstract

A comparative assessment of market-based climate policy instruments –carbon tax vs. ETS– for emission reduction in the Mexican electricity sector is presented. Model-based scenarios of different tax and cap levels were simulated on an existing Balmorel partial equilibrium model populated with data from the Mexican electricity system. The simulation results served to compare the performance of both instruments according to economic criteria. The analysis was further developed with the empirical evidence obtained from international experiences with both instruments, allowing to conclude on the first-best normative instrument based on an economic approach. The assessment was complemented with a political feasibility perspective, through the development of an on-line survey and in-depth interviews with representatives of the relevant stakeholder groups within the country. The first-best instrument was not favoured by the stakeholders, but the study allowed to hint a second-best alternative with a better probability of being fully implemented. The results of this project are useful to guide the necessary debate surrounding the selection of the most appropriate carbon-pricing mechanism for emissions reduction in the country, in particular in the electricity sector.

A wide-coverage carbon tax with no exemptions and with revenue-recycling mechanisms, gradually increasing to 15 USD/tCO2 would be the first-best instrument from the economic perspective. However, when complementing the analysis with the political feasibility perspective, the most appropriate instrument for emissions reduction in the Mexican electricity sector is an emissions trading system with the cap set as the conditional target of the INDCs, with auctioned allowance allocation and an auctioning floor-price, set at a similar but lower value than the equivalent carbon tax. Such an instrument is in line with the priorities of the stakeholder groups and would generate a stable price signal, allowing for the earmarking of carbon revenue, and would avoid exempting natural gas from carbon pricing.

Keywords Mexico, market-based instruments, carbon-pricing, climate policy, electricity, political economy, Balmorel

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List of Abbreviations

CCE	Consejo Coordinador Empresarial (Enterprise coordination council)
CEL	Certificados de Energías Limpias (Clean energy certificates)
CENACE	Centro Nacional de Control de Energía (National TSO/ISO)
CFE	Comisión Federal de Electricidad (State-owned electric utility)
CICC	Comisión Intersecretarial de Cambio Climático (Inter-ministerial commission on climate change)
CONCAMIN	Confederación de Cámaras Industriales (Confederation of industrial chambers)
COP	Conference of the Parties, decision-making body of the UNFCCC
ETS	Emissions Trading Scheme
GHG	Greenhouse gases
INDC	Intended Nationally Determined Contributions
INECC	Instituto Nacional de Ecología y Cambio Climático (National institute for ecology and climate change)
IPCC	Intergovernmental Panel on Climate Change
LGCC	Ley General de Cambio Climático (General law on climate change)
NGO	Non-Governmental Organization
PIE	Productor Independiente Energía (Independent energy producer)
PRODESEN	Programa de Desarrollo del Sistema Eléctrico Nacional (National electricity system development program)
RENE	Registro Nacional de Emisiones (National emissions registry)
SEN	Sistema Eléctrico Nacional (National electricity system)
SENER	Secretaría de Energía (Mexican Ministry of energy)
SEMARNAT	Secretaría de Medio Ambiente y Recursos Naturales (Mexican Ministry of environment and natural resources)
SHCP	Secretaría de Hacienda y Crédito Público (Mexican Ministry of finance and public credit)
TSO/ISO	Transmission System Operator/Independent System Operator
UNFCCC	United Nations Framework Convention on Climate Change

List of Units

tCO_2 / tCO_{2eq}	Metric ton of carbon dioxide / Concentration of a given mixture of GHG which would cause the same amount of radiative forcing as one tCO_2
kt / Mt	Kiloton (10^3 ton) / Megaton (10^6 ton)
GJ / TJ	Gigajoules (10^9 joule) / Terajoules (10^{12} joule)
MW / GW	Megawatts (10^6 watt) / Gigawatts (10^9 watt)
kWh / MWh	Kilowatt·hour /Megawatt·hour (10^3 kWh)

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1 Introduction

1.1 Motivation

Anthropogenic greenhouse gases (GHG) emissions and their atmospheric accumulation has been increasing average global temperature since the mid-20th century. This change in climatic conditions impacts upon natural and human systems, and threatens to cause substantial damages in the short, medium and long-term (Intergovernmental Panel on Climate Change, 2014).

As global consensus is reached on the urgency of climate change mitigation, interest has gone to the policies required to reduce GHG emissions. Climate change mitigation is more complex than traditional environmental problem-solving: the impacts are global and long-term and there is a lot of uncertainty surrounding its consequences. Furthermore, the costs and benefits of mitigation policies are unevenly distributed both geographically and temporally (Goulder and Pizer, 2006). The Paris Agreement signed in 2015[1] at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) has set the world on track to international climate cooperation to keep the global average temperature "well below 2°C" (United Nations, 2015).

Mexico was the second country in the world to adopt a comprehensive legislation package on climate change, after the UK (International Energy Agency, 2016) (SEMARNAT, 2016a), and the first developing country[2] to set an absolute emissions reduction target for 2050 (ECOFYS and Climate Analytics, 2012). There is good availability of emissions data and an institutional framework which provides a solid ground for climate policy-making (ECOFYS and Climate Analytics, 2012). Mexico has been considered the country with the highest mitigation capability among a group which also comprises Brazil, India, China and South Africa, because it has "the highest GDP[3] per capita, the highest HDI[4], the lowest consumption share of coal, and a relatively high proportion of the service sector" (Rong, 2010).

The power sector accounts for approximately 20% of the national emissions. The recent energy reform (2013) structurally transformed the power sector and created an electricity market, offering the possibility to introduce cost-efficient market-based instruments to reduce the GHG emissions from the electricity generation. Timid attempts to introduce a carbon tax and a voluntary tradeable emissions' permits system have been made. However, the carbon tax is far below the optimal carbon price and the tradeable permits system is currently in an exercise phase, prior to the pilot phase.

Economic research on climate policy instruments has traditionally been normative, focusing on selecting and designing an instrument which will maximize the social welfare (Goulder and Pizer, 2006). Although valuable, this approach lacks a positive evaluation of the political feasibility of such optimally designed instruments, as political barriers frequently lead to selecting or designing sub-optimal alternatives to these instruments (Jenkins, 2014).

The motivation for this thesis is to contribute to Mexico's climate change mitigation efforts by providing an assessment of two climate market-based instruments – a carbon tax and tradeable emission permits – based on following complementary approaches: determine the normative ideal instrument given the economical context and structure of the power sector, while assessing its political feasibility and exploring the possible sub-optimally designed instruments which could emerge. This will guide the recommendations on which of these instruments should and could, from the perspective of the electricity sector, become the cornerstone of Mexican climate policy.

[1] It was ratified in October 2016 and entered into force in November 2016.
[2] A categorization based on a country's basic economic conditions, as defined in the UN's *World Economic Situation and Prospects* report (United Nations, 2017).
[3] Gross domestic product.
[4] Human development index.

1.2 Objective

This project aims to assess and compare the cost-effectiveness of a carbon tax and an emissions trading scheme (ETS) for the Mexican electricity sector, as well as explore the political feasibility and most appropriate measures for introducing new policy instruments for emission reduction in the country.

The research question is: *Which policy instrument, carbon tax or ETS, is the most appropriate for reducing GHG emissions in the Mexican power sector, in terms of economic impacts and political feasibility?*

The research question can be elaborated in the following way:

- Which instrument (carbon tax/ETS) would provide the most cost-effective way of reducing GHG emissions in the Mexican power sector?
- Is it politically feasible to introduce a carbon tax or an ETS in Mexico?

The factors determining the appropriateness of GHG emission reduction instruments for the Mexican power sector are identified through: (i) the development model-based scenarios of the different instruments in the Mexican electricity sector; (ii) a literature review of the empirical evidence of international experiences; and (iii) an on-line survey and in-depth interviews with representatives of the relevant stakeholder groups within the country. The results of the model-based scenarios' and the empirical evidence of international experiences are analyzed per a set of economic effectiveness criteria. The interviews are analyzed according to a framework of political feasibility adopted from the political economy public choice approach.

The report is organized as follows: The next chapter will introduce the policy instruments and the framework for their assessment. Chapter 3 will outline the methods of research, followed by Chapter 4 which describes the history and current state of the Mexican electricity system and climate policy. Chapter 5 presents the results. The final conclusions and policy recommendations are presented in Chapter 6.

2 Theoretical background

This section aims to introduce the objects of our analysis (emission trading system and carbon tax) by placing them in the context of climate policy instruments taxonomy. Furthermore, it presents the analytical framework with which the instruments will be assessed.

2.1 Policy instruments for GHG emissions reductions

The problem of how to reduce or regulate the activities carried out by an entity or group of entities which negatively affects others (for example by emitting GHG emissions) but simultaneously provides social benefits (for example providing energy services) is a complex one. A range of instruments have emerged to tackle this challenge. In its taxonomy of domestic policy instruments to tackle climate change, Stavins (1997) divides them into two categories: command-and-control instruments and market-based instruments (Stavins, 1997).

2.1.1 COMMAND AND CONTROL INSTRUMENTS

Command and control instruments "*set standards and directly regulate the activities of firms and individuals*" (Stavins, 1997). The goal set by the regulatory agency can take many forms: emission limits, bans, technology standards, etc. (Stavins, 1997). Command and control instruments may achieve emission reductions, but generally do so in an inefficient way, as little to no flexibility is given to firms. There are situations when command and control instruments could be efficient relative to alternative instruments, particularly if the latter have high transaction costs (Stavins, 1997).

2.1.2 MARKET-BASED INSTRUMENTS

Market-based instruments such as taxes and tradeable emission permits are preferred when there is important variation in the marginal abatement costs across economic sectors and subsectors (as is the case for GHG emissions), because these instruments equalize the costs and ensure emission reductions are achieved in the most cost-efficient way (Hansjürgens, 2005).

A main difference between taxes and tradeable permits is the subject to whom they assign property rights. If property rights over the environment are assigned to the government (Pigouvian approach), it has the right to charge a fee, the tax, for its use (Convery, 2015). On the other hand, property rights can be allocated to emitters and those affected by emissions (Coasian approach), expecting they will reach an optimal emission reduction through bargaining (Coase, 1960); in practice, the government assigns limited property rights over pollution to emitters and then facilitates the negotiation between them (Convery, 2015).

In the context of climate change mitigation, these two instruments are also called *carbon pricing* instruments, as they price carbon either directly (carbon tax) or indirectly (emissions trading system, ETS) (World Bank Group, 2016).

PIGOUVIAN TAX

A Pigouvian tax (in the context of GHG emissions reduction) is the amount of money per unit of emissions which corresponds to the aggregate marginal damage imposed on society at the efficient emission level (i.e. emission level corresponding to the crossing of the marginal abatement costs and marginal abatement benefits curves) (Kolstad, 2000). The role of a Pigouvian tax is to "internalize the externalities", by making the emitting firm pay for the damage it imposes on others (Baumol and Oates, 1988). As emitting becomes more expensive, demand for the "production of emissions" (either from the firm itself or from final consumers) is reduced.

A tax can be applied at different points of the fossil fuel utilization chain, ranging from upstream fuel extraction to mid-stream fuel-to-energy conversion to downstream end use (Stavins, 1997). The tax may be levied on the energy content or on the carbon content, although for emissions reduction a tax on the carbon content (carbon tax) is significantly less costly (Stavins, 1997). A very important component of carbon tax design lays in the utilization of revenue: 1. The tax revenue can be directed towards specific *earmarked* environmental programs, 2. the revenue can become part of the general government budget, or 3. the revenue is used to reduce existing taxes (such as income-tax) or returned in the form of tax rebates, the tax system remaining overall *revenue neutral* [5] (Andersen, 2009; Carl and Fedor, 2016). The use of carbon revenue in the majority of countries is a mix of these alternatives (Carl and Fedor, 2016). Switzerland is the country with the largest share of revenue (33%) from its carbon tax to be earmarked for environmental spending (Carl and Fedor, 2016). Examples of countries where carbon tax revenue goes to general spending are Ireland and Iceland (Carl and Fedor, 2016). Nordic countries (Sweden, Denmark, Finland, Norway) launched their *revenue neutral* environmental tax reforms (ETR) in the 90s (Bosquet, 2000), and the most recent example of such kind of carbon revenue utilization is presented by the British Columbia carbon tax (Murray and Rivers, 2015).

TRADEABLE PERMITS

In an emission permits trading system an emissions quota is set and permits to emit are allocated to the actors within the scheme (Baumol and Oates, 1988). The emitting entities decide – based on the market-clearing *shadow price* that naturally sets as a function of supply and demand – whether to introduce new abatement measures or to buy emission permits (Hansjürgens, 2005). Entities with high abatement marginal costs will prefer to buy permits, whereas entities with lower abatement marginal costs will chose to abate and sell the excess permits; emissions are reduced where it is cheaper to do so (Hansjürgens, 2005). Under such system, and as opposed to a carbon tax, emissions can never go over the threshold, independently of economic growth or inflation (Baumol and Oates, 1988).

Emission trading systems can be of two forms: credit-based or cap-and-trade (Hansjürgens, 2005). A credit-based system has a strong command-and-control component: all entities must comply with a specific emissions standard set by the regulatory agency, and can trade with the emission permits that are above this threshold (Hansjürgens, 2005). A cap-and-trade system is fully market-based: all of the entity's emissions can be traded (Hansjürgens, 2005). "First generation" emission trading systems (Lead Trading Program and a variety of air quality policies in the 1970s in the U.S.) were credit-based systems (Hansjürgens, 2005). The first cap-and-trade system was introduced with the SO_2 allowance trading program in the U.S. (1995), and was for long the "most important experience in emissions trading" [11]. The European Emission Trading Scheme (ETS) was the first cap-and-trade system to deal with GHG emissions (Hansjürgens, 2005).

Emission trading systems may also be categorized according to the type of cap: absolute or relative (Weishaar, 2007). An absolute cap, as the name suggests, simply means to express a cap in terms of maximum allowed emissions in the system (Weishaar, 2007). A relative cap is expressed in terms of emissions per GDP (Zeng et al., 2016). Emission permits may be allocated to firms for free or through an auction (Morgenstern, 2005). Free permits can be allocated according to historical emissions (usually called *grandfathering*) or based on relative production standards (Weishaar, 2007). As with the carbon tax, emissions can be capped at different points of the fossil fuel chain (Morgenstern, 2005).

It has been argued that real-world emissions trading systems are likely subject to extreme price variations (Borenstein et al., 2015). A well designed price-collar reduces the risk of price volatility (Schmalensee and Stavins, 2015). A price floor ensures a stable price signal for low-carbon investments, effectively dealing with economic crisis as well as with the interaction with other climate policies (International Carbon Action Partnership, 2017). An alternative stability mechanism is a quantity collar (price and ceiling on the amount of allowances available in the market), such as the market stability reserve (MSR) which has been proposed for the EU ETS (International Carbon Action Partnership, 2017).

2.2 Analytical framework for climate policy instrument assessment

The assessment of climate policy instruments is traditionally performed through a normative economic approach: *what is the most cost-efficient instrument, which optimally distributes the costs and benefits of the policy?* Such an assessment can be complemented with a positive[6] political economy evaluation of the instruments in terms of its political feasibility. In this line, Stavins (1997) argues that the most important assessment criteria for climate policy instruments are efficiency, distributional effects, and political feasibility (Stavins, 1997). A similar framework will be used in this research, assessing the instruments from the economic and political feasibility approaches, using the criteria described below.

[5] Proponents of a *revenue neutral* aim for an environmental tax reform which shifts the taxation burden from 'goods' (income) to 'bads' (emissions) (Andersen, 2009).
[6] Normative theory defines what *should be*, positive reality describes what *is* in a neutral way.

2.2.1 Economic approach

Economic efficiency comes into play in various stages of the pollution control policy design. Initially, a desirable *efficient* amount of pollution must be determined – a level of pollution which balances the benefits obtained by society from the goods and services produced by the emitting entity against the benefits obtained from protecting the environment from such pollution (Kolstad, 2000). Once this level of pollution has been set, the responsibility for emissions control must be allocated to the emitting entities in an *efficient* way (Kolstad, 2000): equalizing marginal abatement costs (Russell, 2001). The latter is one of the most compelling arguments for using market-based instruments. However, efficiency is not the sole economic metric, and the relevant economic perspective criteria are defined as follows:

Static efficiency

In a static setting, it is assumed that there is an constant number of emitters with a fixed level of production, and that competition among the producers is perfect (Russell, 2001). To be efficient in this context simply means maximizing social welfare, and more specifically reducing emissions in the most cost-effective way using existing abatement technology (Duval, 2008). If the marginal cost and benefit curves of emissions abatement are known, it is possible to obtain the optimal point of static efficiency, around which a policy instrument should be designed. The analysis of welfare maximization is usually performed with the Pareto criterion, which states that resource allocation is efficient "*if there is no feasible reallocation that can raise the welfare of one economic agent without lowering the welfare of some other economic agent*" (Black et al., 2009).

In a situation of perfect foresight and certainty, there would be no fundamental difference between the instruments, as the carbon tax and the carbon shadow price set by the market in an ETS are equivalent (Baumol and Oates, 1988; Speck, 1999). However, uncertainty in both the marginal abatement cost and benefits curves is the norm, and deviations from the optimal level of tax or of cap are to be expected. It has been shown (see Figure 1) that in such situations a tax is to be preferred for steep marginal cost curves and flat marginal benefit curves (social loss associated with an ETS is larger than for the tax), while the opposite is true for an ETS (Baumol and Oates, 1988; Weitzman, 1974).

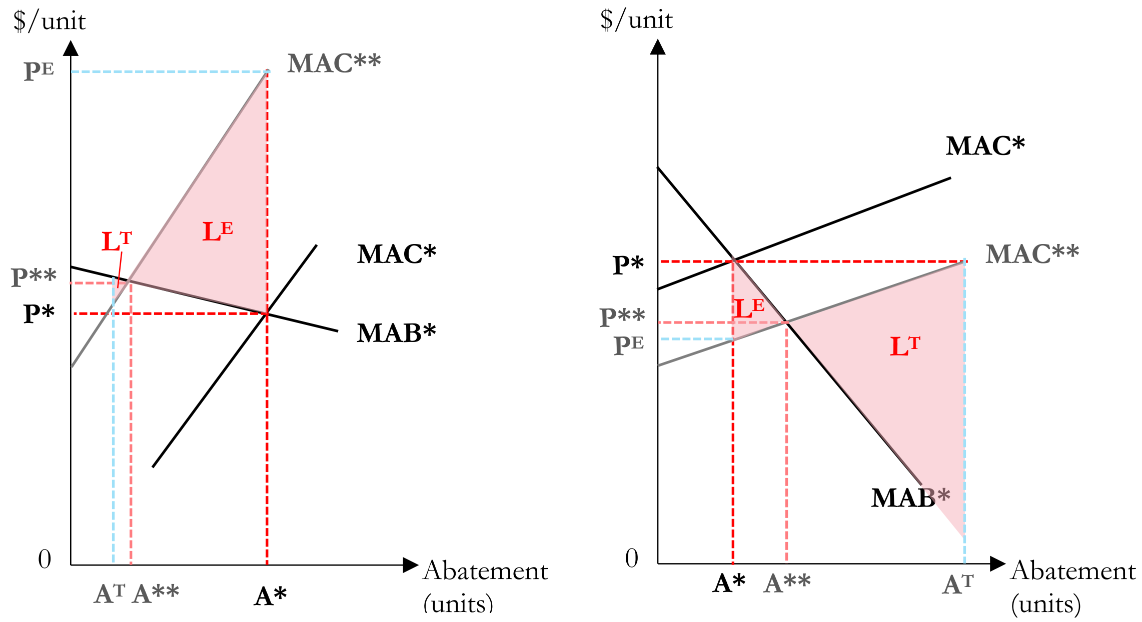

Figure 1. Social loss for a carbon tax (LT) and for an ETS (LE) when the marginal abatement costs (MAC) curve is uncertain, for varying MAC and marginal abatement benefits (MAB) curve steepness. P: equilibrium price based on expected MAC curve; P**: real equilibrium price; P^E: permit price in an ETS; A^T: abatement with a carbon tax; MAC*: expected abatement costs curve; MAC**: real abatement costs curve. Based on (Baumol and Oates, 1988).*

Environmental effectiveness

In response to the uncertainty in costs and benefits which surrounds GHG emission abatement policy-making, the criterion of environmental effectiveness will be included in the present assessment. This is particularly important when assessing a carbon tax, since even a tax set at a theoretically optimal level could result in lower emission abatement than intended, posing a serious threat of not achieving the national emissions target.

IMPACTS ON INDUSTRY COMPETITIVENESS

The risk of a loss of international competitiveness of the energy-intensive industries has been a core concern of environmental policy-making since the initial environmental tax reforms (ETR) in the beginning of the 90s (Andersen et al., 2007). This fear has been extended to other carbon pricing mechanisms such as the ETS. A change in the international competitiveness of a company can be defined as a "*change in operating margin resulting from a change in output, and/or a change in costs, and/or a change in prices*" (European Commission Directorate General for the Environment et al., 2006). However, this refers only to individual impact on companies. If used as a criterion for policy mechanism evaluation, it is important to consider the overall impact on the country (Andersen et al., 2007). A better indication of competitiveness decrease is a modification in investment decisions or in trade patterns at national level (Reinaud, 2008).

DYNAMIC EFFICIENCY

In a dynamic setting the number of emitters, their level of production, their abatement technologies, etc., are changing in reaction to endogenous (climate policy) or exogenous (changes in consumer preferences) factors (Russell, 2001). Economic growth and inflation have an additional dynamic effect (Hansjürgens, 2005). It is difficult to define an optimal course of action leading to dynamic efficiency (Russell, 2001); however, an assessment of the dynamic efficiency of a policy instrument can be approximated by determining the level up to which it provides R&D and technology diffusion incentives (Duval, 2008).

DISTRIBUTIONAL EFFECTS

Distributional effects refer to how the costs and benefits of a policy instrument are distributed through different segments of society (Fullerton, 2008). Instruments are said to be *regressive* if the poorer segments of society bear higher costs and lower benefits than richer segments of society, the opposite being true for a *progressive* instrument (Black et al., 2009). As far as the distributional effects are concerned, a progressive instrument is better than a regressive instrument.

The nature and design of an instrument will strongly impact how progressive or regressive the instrument is. A tax which increases the price of energy (such as a carbon tax) would traditionally be thought to be regressive, since goods such as electricity make up a higher share of a low-income budget (Fullerton, 2011). However, recent research shows that revenue generating policies can be progressive if revenue is used to reduce labor or income-taxes (as part as of revenue-neutral tax reform) (Andersen and Ekins, 2009) or to provide lump-sum rebates for low-income households (Murray and Rivers, 2015).

A climate instrument may also be regressive if it induces firms to invest in capital-intensive abatement technologies, lowering the demand for labor with respect to capital (Fullerton, 2008). Climate policy can also, by restricting the emission levels and thus forcing them to reduce output, create an artificial scarcity for the goods whose production is emission-intensive – when this causes prices to go up, a *scarcity rent* is generated which can be captured by the government (as revenue, when a tax is in place) or by firms (as private profit, when an ETS is in place) (Fullerton, 2008). This situation is regressive as benefits go to high-income firm owners.

2.2.2 POLITICAL FEASIBILITY APPROACH

Dror (1969) argues that political feasibility is an important criterion for policy assessment, stating two main reasons: 1. One must identify whether a policy instrument has a "reasonable probability" of implementation (within a defined time range) to avoid pursuing efforts on irrelevant alternatives; 2. There are political risks and costs associated with the political feasibility of an alternative. However, caution should be exercised about making political feasibility a "dominant" criterion (Dror, 1969). Having an economic *first-best* policy option helps makes more transparent the costs associated with choosing a *second-best* (politically feasible) alternative (Karplus, 2011).

There is a widely recognized gap between normative theory and positive reality (Ellerman, 2015). Despite knowledge of the economically preferable market-based instruments, command-and-control regulation has traditionally been the main instrument of choice (Ellerman, 2015). Similarly, ETS instruments have recently gained in popularity over their the theoretically more efficient[7] carbon tax (Ellerman, 2015). Knowledge of the superior economic effects of a policy instrument is thus insufficient to hypothesize on whether an instrument will be selected (Hahn and Stavins, 1991).

The public choice approach of political economy applies the principles of economics to political science (del Río and Labandeira, 2009). The selection of a policy instrument is characterized as a struggle between policy-makers and various stakeholder groups acting in their own self-interest, the outcomes of which will be determined by the preferences and the relative power of each group (Munaretto and Walz, 2015). The relevance of actors in the policy-making process changes according to the country (Munaretto and Walz, 2015) or the subject matter of the policy which is discussed. The bargaining between the actors impacts both the instrument choice (del Río and Labandeira, 2009) and the design and parameters (carbon price, abatement level) of the instrument (Gawel et al., 2014; Jenkins, 2014), which may potentially deviate from the normative "ideal" instrument (del Río and Labandeira, 2009). To evaluate the climate policy instruments from a political feasibility perspective, the public choice approach will be used; the stakeholder groups whose preferences and relative power are relevant to the selection of the instruments are described below.

Actors involved in climate policy instrument choice

The public choice approach to environmental policy generally categorizes the actors who impact policy-making into four main groups: politicians (seeking re-election), voters, regulated industries and public bureaucrats (Kirchgässner and Schneider, 2003). Keohane et al. (1997) further divides voters into consumers, workers and environmentalists, and adds interest groups such as environmental groups and trade associations (Keohane et al., 1997). In their public choice analysis of the reluctance of Spanish policy-makers to introduce market-based climate policies, Del Río and Labandeira (2009) focus on policy-makers, abatement lobbies, voters, media, and industry. In their assessment of the political feasibility of climate policy instruments for the European Union, authors Munaretto and Walz (2015) have divided the interest groups into: bureaucrats (not subject to re-election), politicians (subject to re-election), environmentalists, industry, research community and emissions trading constituencies (for example carbon market business intermediaries). The latter is relevant only in a situation where an emissions trading system is in place.

In the context of the current analysis, namely the Mexican electricity sector, the relevant actors are:

The *public sector*, includes both elected politicians and non-elected public officials. Elected politicians are usually characterized as seeking re-election, so they can be said to indirectly represent their *voters'* opinions during the decision-making process (Kirchgässner and Schneider, 2003). This doesn't mean that they will necessarily maximize social welfare; rather, they will aim to cultivate support from particular (relatively powerful) subgroups from the electorate (Gawel et al., 2014). Public officials are constrained by the national legislation and international commitments in terms of GHG emissions reduction.

Within the scope of this study, *electricity generators* are those directly responsible for the emissions. Generators may own fossil fuel-based and renewable-based generation. *Industry* represents the largest consumer of electricity, and is thus indirectly responsible for the emissions. It should be noted that industry is also a direct emitter (in processes such as cement or steel production), so their interest in influencing climate policy is two-fold. Industry provides goods and services to the consumers and employment to the workers, and is usually well organized into interest groups, which gives it strong impact in the political arena (Kirchgässner and Schneider, 2003).

Environmental NGOs seek more ambitious climate policy. The *research community* is particularly important in the context of market-based instruments selection, as it will inform the policy-makers on the effects of the policies and it tends to have credibility from the public. The research community can be divided into *academia*, and *consulting (and other services) companies*, the latter being a closer ally of the business community.

[7] Assuming a relatively flat marginal abatement benefits curve.

3 Methods

To carry out a comprehensive evaluation of climate market-based instruments using the economic and political feasibility approaches described in Section 2.2, a combination of quantitative and qualitative methods was used.

The quantitative method utilized was the modeling of different carbon tax and ETS scenarios on a partial equilibrium model previously populated with data from the Mexican electricity system. Results from the simulations, such as the emission abatement, total costs, renewable generation installed capacity or electricity prices, help compare the cost-effectiveness of a carbon tax and an ETS as well as give a preliminary value at which the tax rate or the ETS cap should be set.

Then, a qualitative analysis of international experiences with carbon tax and ETS was performed, to understand the more complex economic impacts which a deterministic static equilibrium model is unable to capture. The economic effects are assessed using the criteria defined in the Section 2.2.1: environmental effectiveness, effects on industrial competitiveness, dynamic efficiency and distributional effects. The modeling together with the qualitative analysis of international experiences allow to recommend the *first-best* instrument (either carbon-tax or ETS, including some broad design features) according to the normative economic approach.

Finally, a qualitative analysis of the political feasibility of the instruments and their design is performed through an on-line survey, as well as semi-structured interviews whose respondents were representatives from the different interest groups involved in the Mexican electricity sector (see Section 2.2.2). Together, these two tools help understand the preferences and the relative power of the different interest groups regarding market-based climate policy instruments. As an outcome of the political feasibility approach, the instrument with a greater probability of being implemented is identified.

The described methods of research (see Figure 2) allow to determine the most appropriate instrument for reducing GHG emissions in the Mexican power sector; an instrument which is suitable from an economic perspective (although perhaps not the first choice), but also with enough probability of being implemented. The methods are described in further detail below.

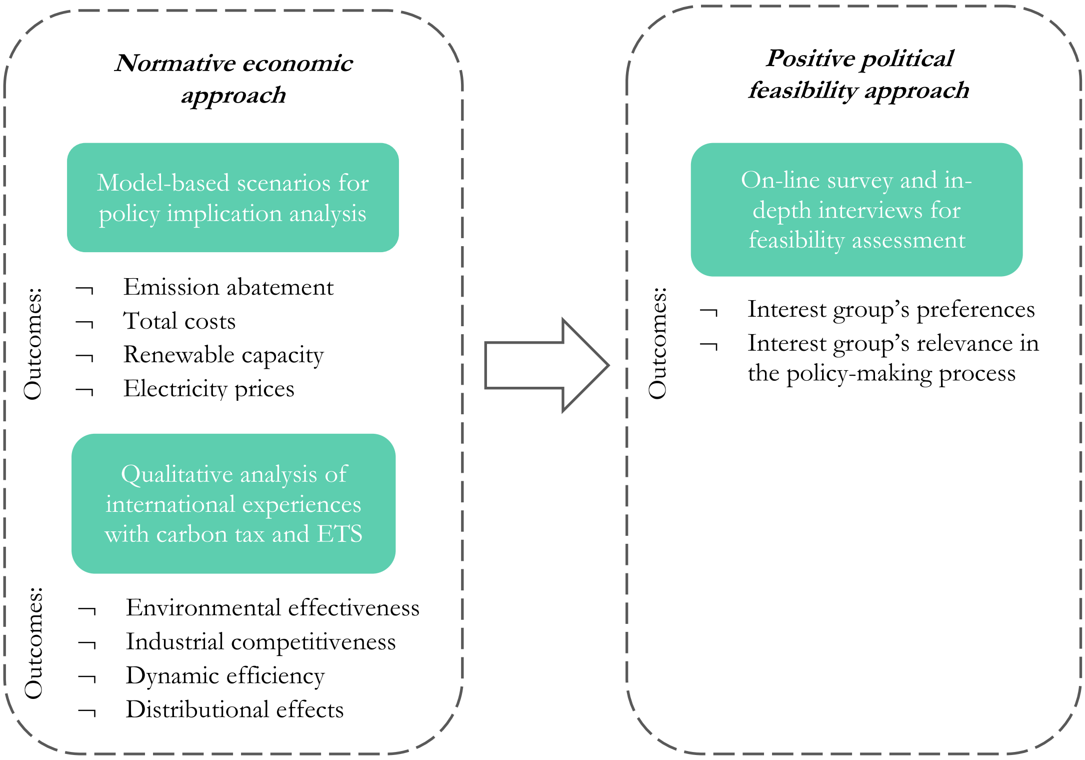

Figure 2. Diagram depicting the methods of the research

3.1 Model-based scenarios for policy implication analysis

To understand the potential impacts of the carbon pricing mechanisms in the Mexican electricity sector, different scenarios were modeled using the open source deterministic partial equilibrium model Balmorel, which had previously been populated with data from the existing and planned Mexican electricity system by the Danish consulting company Ea Energy Analyses (Togeby and Dupont, 2016). The model requires a licensed version of GAMS as a solver.

Balmorel is used for energy system analysis, specifically electricity and combined heat and power systems. Balmorel has been used to assess the impacts on the electricity markets of the Norwegian-Swedish tradeable green certificates (Tveten and Bolkesjø, 2016), to investigate the effects of increased demand side management (DSM) in the Northern European power markets (Tveten et al., 2016), to develop an electricity system Master plan for the Eastern Africa Power Pool (Ea Energy Analyses and Energinet DK, 2014) as well as to simulate renewable energy scenarios for Mexico (Togeby and Dupont, 2016).

The model can invest in new generation/transmission capacity given a technology catalogue. Balmorel may be run in different modes – either *least-cost investment* (optimizes investment and average operational costs) or *least-cost dispatch* (optimizes only operational costs) (Ea Energy Analyses, 2016). For the present research, the model was run first in the *least-cost investment* mode, and the endogenously generated optimal investment values were subsequently used as inputs to run the model in l*east-cost dispatch* mode.

The Balmorel model for the Mexican electricity system is data intensive, and extracting the output results requires a licensed software. For this reason, the simulations were performed in conjunction with the team of researchers which developed the Mexican model, who are currently using it for an alternative research project with the Mexican Ministry of Energy (SENER). The scenarios, data and sensitivity parameters described below have been developed specifically for the present research project.

3.1.1 THE BALMOREL MODEL

In *least-cost investment*, the objective function is a minimization function of the cost of satisfying the electricity demand, thus the costs of electricity generation, fuel consumption, and generation and transmission investments. The latter are annualized using an annualization factor (*a* in the Equation below) which contains the discount rate. The model is myopic; each year is optimized without knowledge of what the situation will be in the future. The model is solved using a continuous linear program solver. The mathematical representation of the objective function is as follows (Dupont, 2017)[8]:

$$\min Z_y = \underbrace{\sum_{g,t} c^e_{g,t} \cdot G^e_{g,t}}_{\text{EG}} + \underbrace{\sum_{g,f,t} c^f_{g,t} \cdot F^f_{g,t}}_{\text{F}} + \underbrace{\sum_{g} (a \cdot c^I_g + c^{fix}_g) I_g}_{\text{GI}} + \underbrace{\sum_{x} a \cdot c^I_x \cdot I_x}_{\text{TI}}$$

Where:

- EG corresponds to variable electricity generation costs: *e*, *g* and *t* are indexes for electricity, technology and time respectively, *c* represents the cost parameter and *G* is the endogenous variable for generation. Generation costs include operation and maintenance costs, as well as taxes.
- F corresponds to fuel consumption costs: *f*, *g* and *t* are indexes for fuel, technology and time respectively, *c* represents the cost parameter and *F* is the endogenous variable for fuel consumption.
- GI corresponds to generation investment: *g*, *I* and *fix* are indexes for technology, investment and fixed costs respectively, *c* represents the cost parameter, *a* is the parameter converting investment into annual costs, and *I* is the endogenous variable for investment in generation capacity.
- TI corresponds to transmission investment: *g* and *I* are indexes for technology and investment respectively, *c* represents the cost parameter, *a* is the parameter converting investment into annual costs, and *I* is the endogenous variable for investment in transmission capacity.
- *y* is an index for year.

[8] The general version of the Balmorel objective function includes heat generation and unit commitment terms; as they are not relevant to the present study, they have not been included.

The optimization is subject to constraints such as balancing of electricity supply and demand, technical constraints (electricity generation is lower than generation capacity, fuel consumption is equal to electricity generation divided by efficiency), transmission constraints, resource availability constraints, policy constraints, among others.

This *least-cost investment* simulation mode aggregates hourly input data into a smaller number of time periods which are expected to have similar characteristics (Ea Energy Analyses, 2016). Time aggregation aims to represent reality while requiring less computing time. Time aggregation varies per geographical location due to different load patterns: for Mexico, hours have been aggregated into 26 seasons (2 weeks each), each season divided into 10 time slots.

Once the optimal generation and transmission investments are found via the *least-cost investment* mode, the values are used as exogenous inputs in the *least-cost dispatch* mode, to find the optimal generation and resulting electricity prices. This optimization is run in hourly simulation mode, performing weekly iterations. Investment costs are no longer part of the cost-minimization objective function.

3.1.2 DATA

In Balmorel, a country can be divided into *regions*. Mexico has been characterized as having 53 regions, which correspond to the transmission regions described in the mapping of the electricity system (see Section 4.2.2). For each of these an annual demand profile is defined, as well as transmission capacity to other regions (Dupont, 2017). Regions can be further disaggregated into *areas*. Each area is characterized as having a generation capacity, investment potentials, energy resources (including variation profiles for renewable sources) and fuel prices. In the case of Mexico, there is mostly a one-to-one relationship between region and area; the exception is that each hydro power plant is assigned to a separate area, to be able to assign them plant-specific water inflow profiles (Dupont, 2017).

As previously mentioned, the model had previously been populated (for a parallel research project) with data from the Mexican electricity system. Data which was disaggregated by area includes the hourly electricity demand (projections to 2030 obtained from the national TSO, CENACE), existing, prospective and soon-to-be decommissioned power plants (obtained from the Ministry of Energy, SENER), renewable resources' geographical availability and hourly-variation profiles as well as constraints on fuel potentials and minimum fuel usage. Additional to the mentioned exogenously determined decommissions, Balmorel can chose to endogenously decommission power plants if their operation is uneconomical. The expected national electricity demand growth to 2030 is shown in Figure 3.

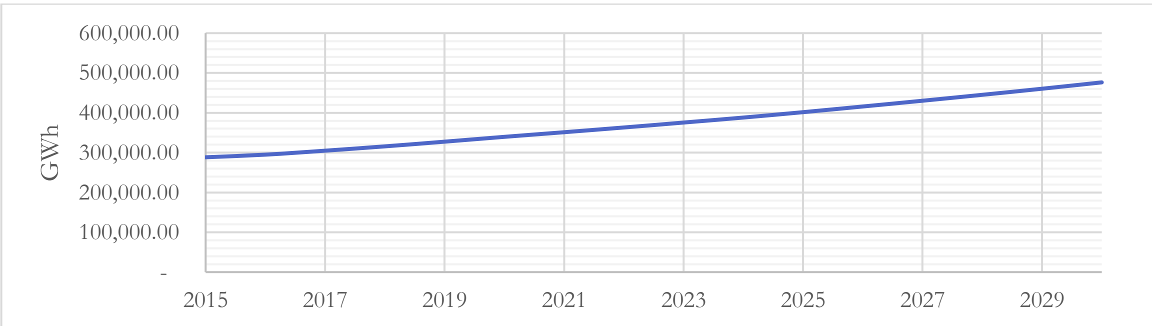

Figure 3. Expected national electricity demand (2015-2030). Source: (SENER, 2016a)

Fuel data includes emission factors, renewable content, and costs (with projections up to 2030). The fuel costs have been updated for the present study, using the recently released Nacional Electricity System Development Program (PRODESEN) 2017 (SENER, 2017). They are presented in Figure 4.

Part of the data input to Balmorel consists of a technology catalogue from which the model can select to invest in both generation and transmission capacity. Generation information includes technology type, fuel, efficiencies, ramp-up/down, losses, as well as investment, maintenance and operation costs. The technology costs were outdated for most of the generation technologies, so they have been updated for the present study using the PRODESEN 2017, as well as renewable energy investment costs predictions up to 2025 (International Renewable Energy Agency, 2016). The costs used in the simulation are presented in Table 1.

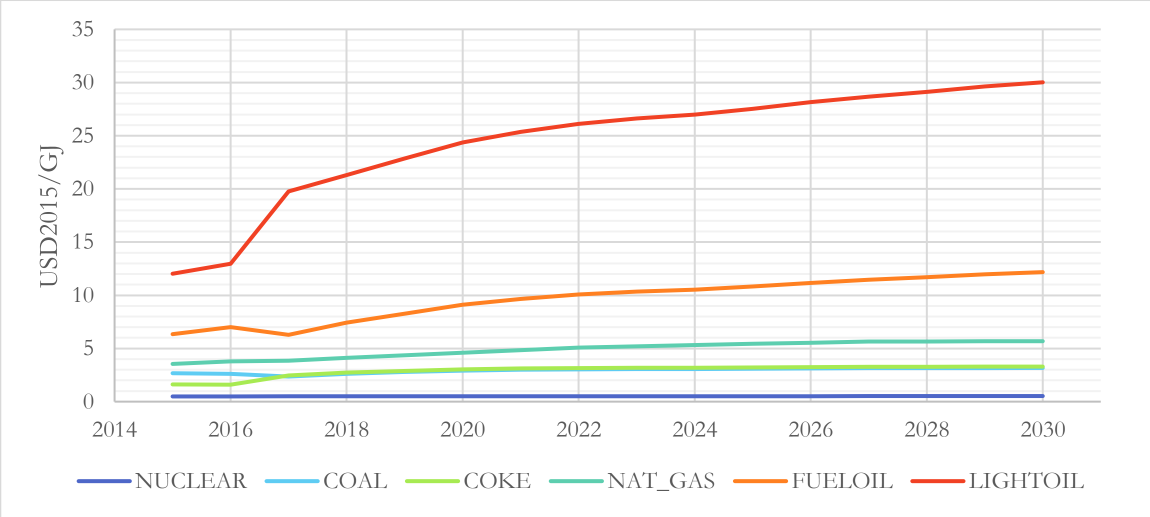

Figure 4. Fuel price trends used for the model-based scenarios (2015-2030). Source: (SENER, 2017).

Table 1. Technology costs used for the model-based scenarios (2015-2030). Source: (International Renewable Energy Agency, 2016; SENER, 2016a, 2017)

Technology	Time frame (if applicable)	Investment costs (MUSD/MW)	Fixed O&M costs (kUSD/MWyear)	Variable O&M costs (USD/MWh)
Biomass		2.73	77.42	0.00
Coal-CCS		3.98	117.99	2.40
Coal-sub		1.85	46.71	2.40
Coal-super		2.21	65.55	2.50
Combined cycle		0.96	15.70	2.80
Gas turbine		0.80	5.00	4.70
Diesel		2.77	62.40	8.10
Nuclear		3.92	99.50	2.40
Wind	2020-2024	1.40	37.50	0.00
Wind	2025-2030	1.31	37.50	0.00
SolarPV	2020-2024	1.24	10.50	0.00
SolarPV	2025-2030	0.82	10.50	0.00
Small hydro	2030-2050	1.90	30.30	0.00
Geothermal	2030-2050	1.86	82.30	0.10
Cogeneration	2030-2050	0.88	15.00	0.99

In addition, the discount rate was set as 10%, as determined by the Ministry of Finance and Public Credit (SHCP) in 2014, having decreased from 12% in the previous years (Secretaría de Hacienda y Crédito Público, 2014). Investments by the state-owned companies such as CFE are subject to a different discount rate (called "Retorno objetivo"), which is to be defined on a case-by-case basis by the SHCP (*Ley de la Industria Eléctrica*, 2014).

3.1.3 SCENARIOS

Scenarios were run up to year 2030, as this is the year up to which official data predictions could be obtained. The modelled years were 2018, 2021, 2024, 2027 and 2030. The reference scenario (REF) simulated a business-as-usual system with no policies in place. Two cap or ETS scenarios were simulated: the low-ambition cap (CAPL) which was constrained by the non-conditional target of the INDCs of reducing GHG emissions by 22% in 2030, compared to a BAU baseline; and a more ambitious (CAPH) with the conditional target of reducing emissions by 36% (Section 4.3.1). The CAPL scenario is a simple linear interpolation between the latest published emission values (2013) and the said non-conditional target for the electricity sector in 2030, for which the government has determined that the electricity sector should contribute to 18% of the total emissions reduction (Gobierno de México, 2015). This corresponds to an abatement of 31% from 2013 to 2030. The share of conditional emission abatement corresponding to the electricity sector for the conditional target is not published. For this reason, the CAPH scenario assumed that to meet the national conditional target of 36% by 2030, all sectors increased their abatement by +14% compared to that needed for the non-conditional target. This corresponds to an emission reduction for the electricity sector of 45% relative to 2013.

There were three tax scenarios: the existing tax (TAXE), a medium-level tax (TAXM) and a high tax (TAXH). The TAXE scenario was set at a constant tax level of 5 USD/tCO_2; this is the level which was recommended in 2013 to be levied on the carbon content of fuels (see Section 4.3.2). TAXM was set to gradually increase to 15 USD/tCO_2, corresponding to the upper bound of the range of tax levels proposed to survey respondents (see Section 5.3.15.3). TAXH level was set to gradually increase to 40 USD/tCO_2, a tax level which would be among the ambitious carbon taxes today. An additional TAXM scenario with natural gas exemption was simulated, to explore the consequences of the present official attitude towards natural gas.

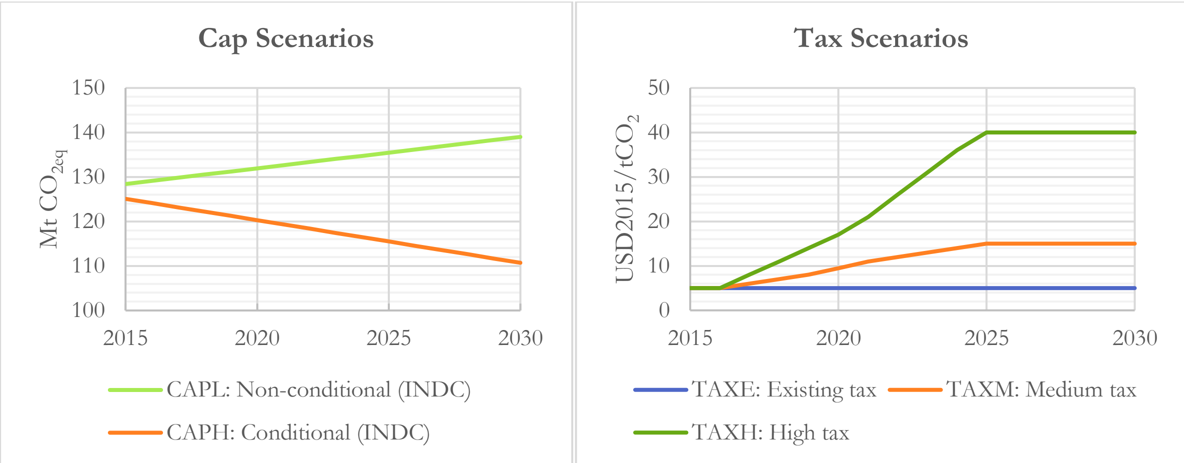

Figure 5. Cap and tax scenarios defined to the model-based simulations.

Further, a sensitivity analysis was performed on the CAPH and the TAXM scenarios. Two of the sensibility analysis parameters were the electricity demand (±10%) and fuel prices (±10%), to understand the risks associated choosing one instrument over the other in situations of uncertainty in the mentioned parameters. The availability of natural gas was also a parameter of the sensitivity analysis, since the fuel's availability and distribution has been identified as a potential bottleneck for the decarbonization of the electricity sector and for the decrease of electricity prices. Low natural gas availability was defined as 80% of the natural gas consumption (including cogeneration) obtained in the REF scenario. Lastly, a reduction of the discount rate was explored, as it has already been argued that the actual level of 10% is too high to incentivize renewable energy generation (Centro Mario Molina, 2014). A level of 5% was arbitrarily chosen; however, it should be noted that such a rate is quite low, given that the 6% discount rate in Chile is the lowest in all of Latin America (Campos et al., 2016). This value was chosen simply to explore the consequences in the behavior in renewable investment, and not to suggest a value for the discount rate. An analysis of the simulations is presented in the Results section.

3.2 Analysis of international experiences with carbon tax and ETS

The international case studies to be analyzed were selected with two criteria in mind: 1. empirical evidence exists and is documented in scientific articles, and 2. the mechanisms have sufficient variation among themselves to obtain valuable lessons from analyzing only a handful of cases. In this line, three cases were selected for the tax mechanism: (i) the environmental tax reform (ETR) in the Nordic countries, (ii) the climate change levy (CCL) in the UK, and further the carbon floor price which was set to function with the EU ETS, and (iii) the carbon tax in British Columbia (Canada). For the ETS/cap-and-trade mechanism, the experiences reviewed are: (i) the EU ETS, (ii) the California cap-and-trade, and (iii) the Chinese pilot ETS. Although the latter is only in the initial stages and not much empirical evidence exists yet, the design of their ETS could be of inspiration for other similarly developing countries. A review of the cases and a summary of the learnings in table format can be found in the Results section.

3.3 Online survey and semi-structured interviews for assessing political feasibility

Data was collected through a survey (in Spanish) to representatives of different interest groups during April and May 2017. For each interest group, the targeted respondents were as follows:

- Public sector: Legislators, public officials from the Federal and State-level Ministries of Environment, Energy, and Finance, as well as the Energy Regulatory Commission
- Industry: Mid-management level; energy, environmental or sustainability managers
- Electricity producers: Mid-management level for large electricity companies, CEOs for small electricity companies
- Academia. Researchers in topics such as the Mexican electricity system and/or climate policy
- NGOs: Climate and energy policy representatives
- Consulting and other services: Analysts of the Mexican energy sector, analysts in climate services

An e-mail invitation to participate in the on-line survey was sent, as well as a reminder two weeks later. The survey was anonymous, and was performed using the GoogleForms platform. 180 invitations were sent, and 47 people responded, thus the response rate being 26%. Table 2 shows a description of the sample. Survey was designed to require approximately 10 minutes, and consisted of 16 closed questions (with varying level of detail), and 3 open questions. The survey questionnaire can be found in Appendix 7.1.

Table 2. Sample description. Characteristics of the respondents.

Academia	13%
Electricity generators	11%
Service companies	30%
NGO	11%
Industry	17%
Public sector	19%

In addition, semi-structured 30-minute long interviews were performed with representatives of the different interest groups. These representatives had previously responded to the survey. Having shown interest in the survey results, they were contacted to do the follow-up interview. At least one representative of each interest group was selected, although in the situations where there is important internal variation within the interest groups (public sector), two or more interviews were programmed. The interviews happened through Skype, and were recorded and transcribed. A list of interviewees can be found in Appendix 7.4. The analysis will be presented in the Results section.

4 The Mexican electricity system and climate policy: history and current state

A comprehensive literature review was performed to understand the institutional, legal and physical infrastructure surrounding the electricity sector, which sets the context in which a carbon tax or ETS would operate. Special attention was given to the recent energy reform, since it is its introduction and the subsequent liberalization of the electricity sector that encourages the use of market-based instruments for GHG emissions reduction. Also, the Mexican climate policy is presented, as well as the accompanying policy instruments. Finally, the policy instruments are positioned in the electricity sector value chain.

4.1 The institutional framework surrounding the electricity sector

The Mexican electricity sector (and energy sector in general) is undergoing a period of profound transformation. As will be described in this section, the legal and institutional framework which had been the status quo for the past decades has been renewed as part of the recent Energy reform. The efficiency of the proposed market-based instruments (carbon tax or ETS) for reducing emissions in the Mexican power sector will depend on the correct functioning (close to perfect competition) of the electricity market in the newly liberalized sector. It is thus very important to understand the new institutional setting, as well as the possible deviations from a perfectly liberalized market which could be apparent in the first phases of this process.

4.1.1 THE CFE MONOPOLY AND THE TRANSITION TO A HYBRID MODEL

The electricity sector was nationalized in the 1960s (Padilla, 2016). The electricity utility company –the Federal electricity commission (CFE)[9]– came in charge of the provision of the public service of electricity, (*Ley del Servicio Público de Energía Eléctrica*, 1975). Electricity tariffs were set by the Ministry of finance and public credit (SHCP) (*Ley del Servicio Público de Energía Eléctrica*, 1975). As electricity generation was considered a public service, private generation was banned, with the exception of generation for self-supply (*Ley del Servicio Público de Energía Eléctrica*, 1975). In 1992, following the North American Free Trade Agreement (NAFTA) with Canada and the United States (Padilla, 2016), the legislation was modified to include new forms of electricity generation which weren't considered public service, and could thus be performed by private entities (*Decreto que reforma, adiciona y deroga diversas disposiciones de la Ley del Servicio Público de Energía Eléctrica.*, 1992):

- Self-supply: electricity generation destined exclusively to own use;
- Cogeneration: electricity generated by using residual heat from a process – the electricity is destined to be used only by the facilities involved in the cogeneration process;
- Small production: electricity generation in power plants <30 MW, to be sold exclusively to the CFE;
- Independent producers (PIE): electricity generation destined to be sold exclusively to the CFE based on long-term agreements;
- Imports: electricity imports destined only to self-supply;
- Exports: electricity generation under the cogeneration, small production and independent production modalities destined to be exported.

The CFE gradually expanded its electricity generation capacity primarily through the PIE-owned combined cycle generation plants (Padilla, 2016). The share of electricity generated by PIE (and sold to CFE) out of the electricity "produced" by CFE was 34% in 2016, up from 11% in 2002[10] (SENER, 2015a). Additionally, legislation allowed a form of bilateral contracts between suppliers and large industrial consumers in which the exchange of electricity from the former to the latter was considered self-supply (IRENA, 2015). As a result, a parallel private electricity market emerged which used the National electricity grid for transmission

[9] A second utility company existed, the now extint Companía de Luz y Fuerza del Centro (LYFC).
[10] Earliest year for which data is available.

and had tariffs 5-10% lower than those set by the SHCP (Padilla, 2016). The modality of self-supply became the largest source of renewable energy installed capacity in those years (IRENA, 2015).

4.1.2 The Energy Reform

In December 2013, a number of energy-related legal provisions from the Mexican Constitution were modified in what is known as the "*Energy Reform*" ("Tracking the Progress of Mexico's Power Sector Reform," 2016), with complementary laws published in 2014 and 2015. The aim of the reform is a structural transformation of the Energy sector, which for the electricity sector means: reducing the share of electricity consumption satisfied by public providers, unbundling the vertically integrated utility company, and allowing private competition in the electricity generation and commercialization (Padilla, 2016).

Commercial exchange between generators and consumers is now permitted (Rosellón and Zenón, 2016), while the government, in the figure of the independent system operator (ISO) –the CENACE–, maintains the responsibility over electricity transmission and distribution, as well as decision capacity over the electricity dispatch, and operates the electricity market (*Ley de la Industria Eléctrica*, 2014).

Electricity supply is divided into basic and qualified. Basic supply is a public service, and will continue to be provided at regulated tariffs [7]. Initially the main basic supplier will be CFE, but additional ones will enter the market through competitive auctions performed by the ISO [8]. The qualified user status is discretionary, and requires an electricity demand higher or equal to a threshold. This limit has been set at 3 MW for the first year of validity of the *Law of the electricity sector*, 2 MW for the second year, and 1 MW at the end of the second year (SENER, 2016b). Qualified users purchase their electricity through the wholesale market in conditions of free competition [8].

4.1.3 Unbundling the Electricity Sector

The Energy Reform launches the vertical and horizontal unbundling of the electric utility company, CFE. Through all the newly created subsidiary companies, CFE may continue to carry out generation, transmission, distribution and commercialization activities (SENER, 2016a) (International Energy Agency, 2016), through the new institutional structure which can be observed in Figure 6.

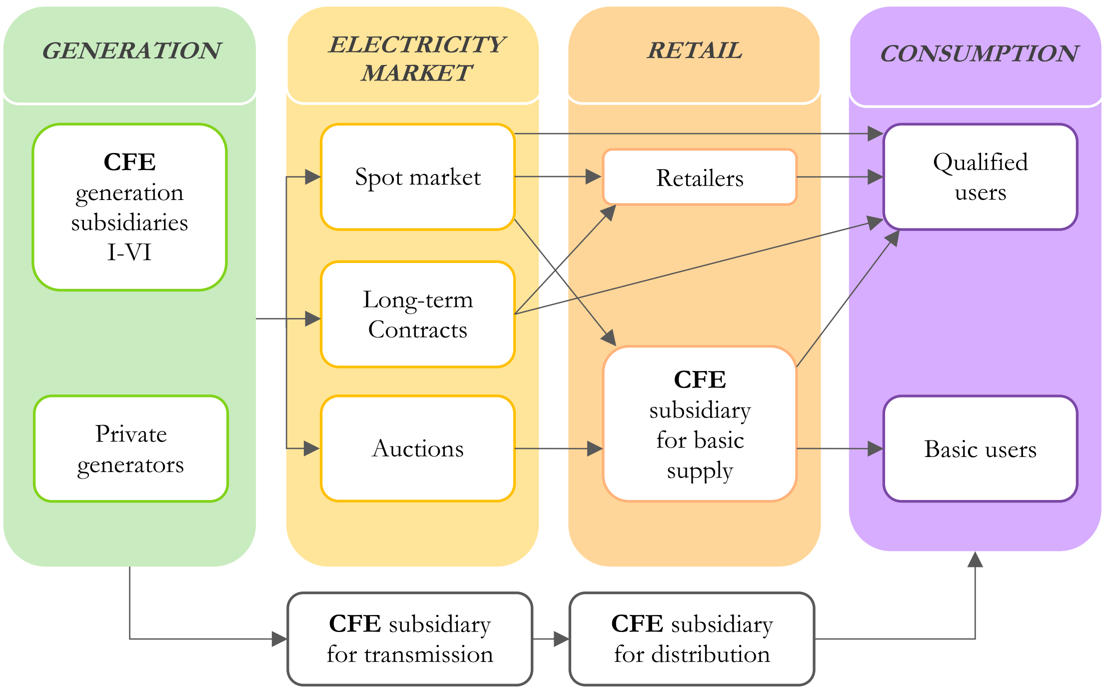

Figure 6. Structure of the Mexican electricity sector and participation of CFE subsidiaries. Adapted from (International Energy Agency, 2016), (Comisión Federal de Electricidad, 2016).

As previously mentioned, only qualified users will pay a liberalized electricity tariff, as they are the only ones able to buy electricity from the spot market and/or from non-basic supply retailers. The rest of users (basic users) will until further notice pay a regulated tariff to the CFE subsidiary for basic supply, which will in turn buy electricity from both private generators and CFE generation subsidiaries. The difference between the real costs and the regulated tariff will be subsidized by the Ministry of Finance and Public Credit (SHCP) (International Energy Agency, 2016). In this context, the efficiency of using market-based instruments for emissions reduction in the electricity sector will be hampered and lower than optimal.

4.2 The electricity system

The previous section described the existing legal and institutional framework within which climate policy instruments for the electricity sector will develop. This section describes the energy system, the physical infrastructure and the operation of the electricity sector, along with the greenhouse gas emissions associated with it.

4.2.1 National energy balance

As a way of understanding the reasoning behind the development of the Mexican electricity system, it is important to have a glance at the bigger picture of the national energy system and the principal energy resources. In 2015, the total energy consumption of the country was for the first time larger than total primary energy production (SENER, 2016c). Primary energy production in 2015 was 8261 PJ, of which 61% was crude oil production and 245% natural gas production (SENER, 2015a).

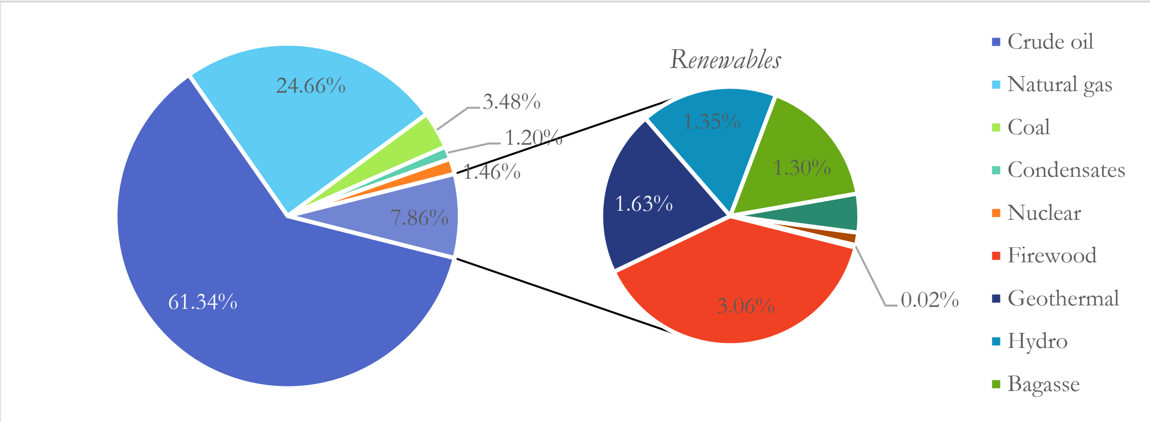

Figure 7. Share of energy sources in primary energy production (2015). Source: (SENER, 2015a)

Primary energy imports consisted only of coal: 223 PJ in 2015. Secondary energy imports totaled 2681 PJ (versus 3681 PJ of secondary energy transformed nationally); of these, 44% was dry gas and 30% was gasoline. The national dependence on imported natural gas is evident, as around 70% of the natural gas imports come from the United States (SENER, 2016a). Crude oil exports represented almost 85% of all energy exports (SENER, 2015a).

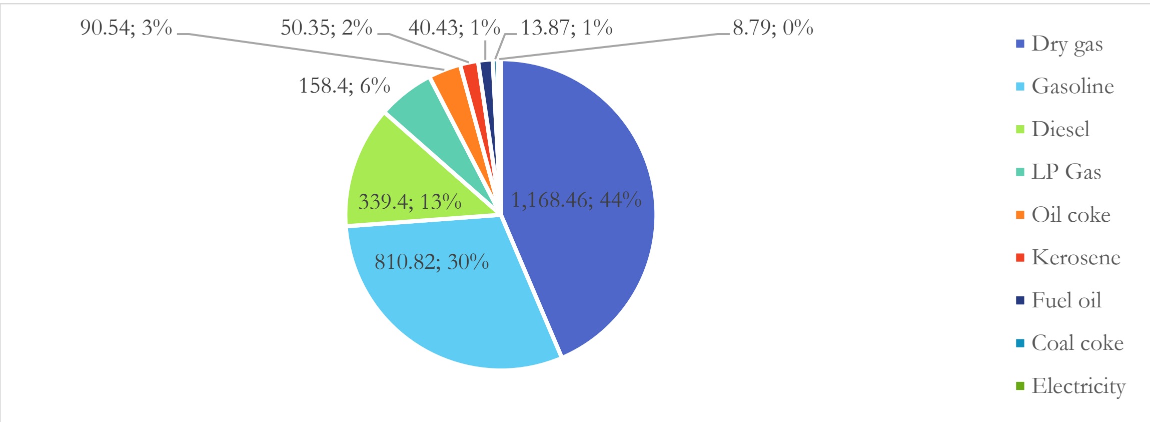

Figure 8. Secondary energy imports by type of energy carrier (2015), in PJ and %. Source: (SENER, 2015a)

The latest complete inventory was published by the National Institute for Ecology and Climate Change (INECC) for the year 2013. Total GHG emissions were 665.3 $MtCO_{2eq}$. Sinks represented 172.9 $MtCO_{2eq.}$, and black carbon emissions 112.6 $MtCO_{2eq}$. As can be observed in Figure 9, power generation is responsible for almost 20% of all the GHG emissions in Mexico; only the transport sector has a larger share of the total emissions. The trend that GHG emissions have followed since 1990 can be seen in Figure 10. Although a downward trend can be observed from 2011 to 2013, there is still no evidence to suggest a decoupling of emissions and GDP (SEMARNAT, 2016a).

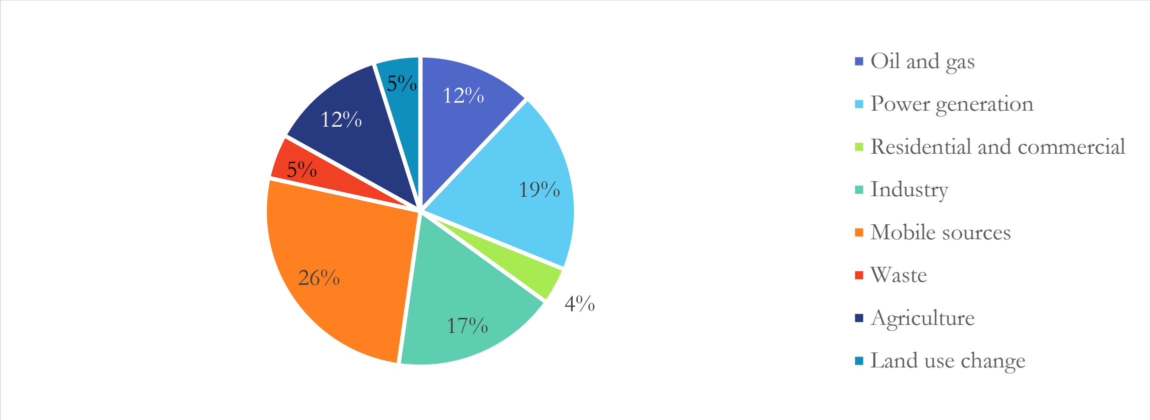

Figure 9. Share of Mexican GHG emissions per sector (2013). Source:("Tabla del Inventario Nacional de Emisiones de Gases y Compuestos de Efecto Invernadero 2013," 2013)

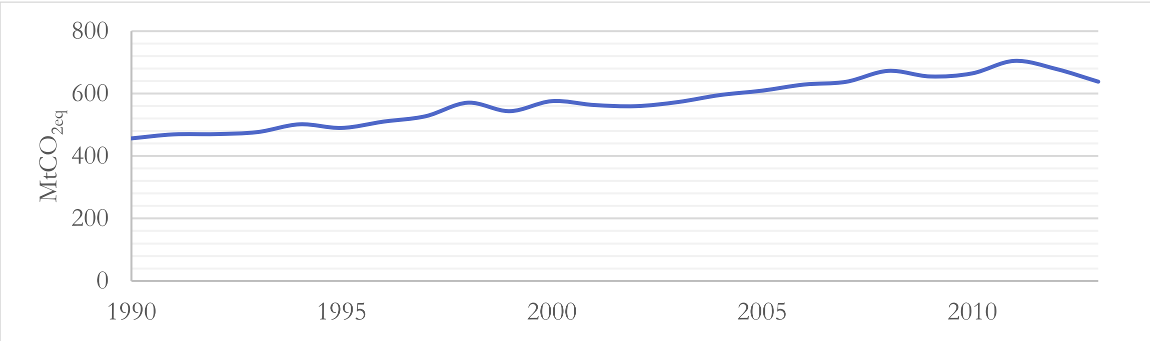

Figure 10. Historical GHG emissions (1990-2010), including LULUCF. Source: (UNFCCC, 2013)

4.2.2 THE PHYSICAL INFRASTRUCTURE

As of 2015, Mexico had 66 GW of installed capacity. CFE still owns and operates most of the electricity generation in the country, although this is expected to change as privately-owned generation plants start to operate. As shown in Table 3, almost 80% of the clean installed capacity corresponds to hydropower plants. Mexico has only one Nuclear power station of 1510 MW (SENER, 2016a).

Table 3. Installed electricity generation capacity (2015), in MW. Source: (SENER, 2015a)

Subtotal CFE	*54,853*
Thermal	34,358
Steam turbine	11,399
Combined cycle	19,918
Gas turbine	2,739
Internal combustion	301
Coal	5,378
Dual	0
Nuclear	1,510
Geothermal	874
Wind	699
Hydro	12,028
Solar PV	6
Subtotal Non-CFE licensed producers	*11,542*
Total	**66,395**

The national transmission grid is divided into 53 transmission regions. Forty-five of these are part of the interconnected national system (SIN), while two smaller systems in the Baja California peninsula connect 3 and 4 regions respectively, and one region (Mulegé) exists in isolation (SENER, 2016a) (see Figure 11).

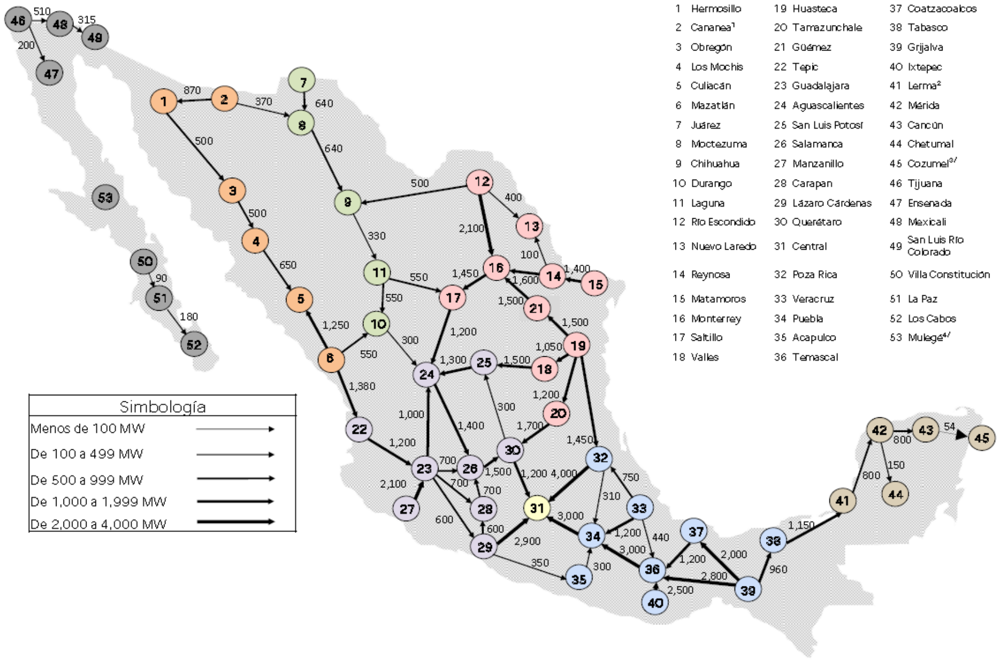

Figure 11. The 53 transmission regions in Mexico and their interconnections (2015). Taken from: (SENER, 2016a)

4.2.3 ELECTRICITY GENERATION AND CONSUMPTION

Technology: In terms of electricity generation, combined cycle represents around 50% of all electricity generated by CFE, as can be observed from Table 4. Most of the combined cycle generation is concentrated in the northern part of the country, where 80% of the gas pipelines are located, as well as more than half of the domestic natural gas production (SENER, 2016a).

Table 4. Electricity generation by technology (2015), in GWh. Source: (SENER, 2015a)

Subtotal CFE	*261,066.8*
Thermal	177,148.9
Steam turbine	35,673.2
Combined cycle	134,486.6
Gas turbine	5,281.1
Internal combustion	1,707.9
Coal	3,475.2
Dual	30,124.0
Nuclear	6,291.2
Geothermal	11,577.1
Wind	2,386.9
Hydro	30,050.8
Solar PV	12.8
Subtotal Non-CFE licensed producers	*33,301.4*
Total	**294,368.2**

Fuels: Until the end of the 20th century, fuel oil was the main fuel used in the electricity generation in Mexico. In the early 2000s, low natural gas prices and the combined cycle technology made natural gas overcome fuel oil as the main fuel in this sector (González Santaló, 2009). In 2015, fuel oil still represented 16% of the electricity generation (in terms of total contained energy), behind coal (24%) and natural gas (33%) (see Table 5). The trend away from fuel oil has switched the sourcing of primary energy for electricity generation from local production (oil) to imports (coal and gas) (González Santaló, 2009), which explains the large coal and natural gas imports described earlier.

Table 5. Fuels used for electricity generation in CFE power plants (2015), in PJ. (Note: Data from the table is an energy balance). Source: (SENER, 2015a)

Coal	-362.45
Nuclear	-120.41
Hydro	-108.46
Geothermal	-133.68
Solar	-0.05
Wind	-0.73
Diesel	-13.60
Fuel oil	-246.29
Dry gas (natural gas)	-494.86
Generated electricity	+619.1

Greenhouse gas emissions: Emissions from power generation totaled almost 127 $MtCO_{2eq}$ in 2013. They can be further disaggregated by generating technology, as can be seen in Table 6. The grid emission factor in 2013 was 0.456 CO_{2eq}/MWh (Gobierno de México, 2014).

Table 6. GHG emissions by the Mexican power sector for year 2013, by technology. Source: ("Tabla del Inventario Nacional de Emisiones de Gases y Compuestos de Efecto Invernadero 2013," 2013)

Technology	Fuel	$MtCO_{2eq}$	%
Coal	Coal and diesel	17.31	14%
Dual	Coal and diesel	17.81	14%
Internal combustion	Fuel oil and diesel	0.95	1%
Combined Cycle (independent producer)	Natural gas and diesel	17.56	26%
Combined Cycle (CFE)	Natural gas and diesel	34.01	14%
Steam turbine	Coal, diesel and natural gas	3.76	27%
Steam turbine with combined cycle	Natural gas	2.00	3%
Gas turbine	Natural gas and diesel	33.22	2%
Total emissions from power generation		**126.61**	

Electricity trade: Electricity trade with neighboring countries is negligible. In 2015, electricity imports and exports totaled 3.9 TWh, or approximately 1.4% of the total generated electricity (SENER, 2015a). Such limited trade is not surprising, since before the reform private power producers in the U.S. could only sell electricity either to CFE or under the modality of self-supply (*Decreto que reforma, adiciona y deroga diversas disposiciones de la Ley del Servicio Público de Energía Eléctrica.*, 1992, *Ley del Servicio Público de Energía Eléctrica*, 1975). An enhanced electricity integration with its neighbors is expected as producers gain the possibility to sell electricity in Mexican electricity market (International Energy Agency, 2016).

Consumption: Electricity sales by CFE in 2015 totaled 212,300 GWh (Comisión Federal de Electricidad, 2015). Out of the net electricity consumption satisfied by CFE, almost 60% is consumed by the industrial sector, around 26% is consumed by the residential sector, 6-7% by the commercial sector, while the agriculture and services consume around 4% each (SENER, 2015a). Peak demand in 2015 was 40,710 MW (SENER, 2016a), slightly more than 60% of total installed capacity.

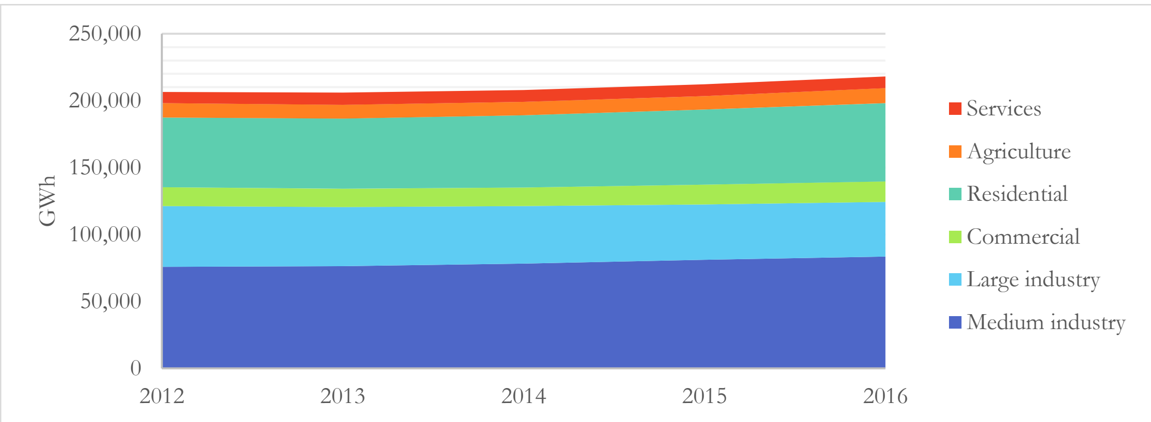

Figure 12. CFE electricity sales by user type. Source: (SENER, 2015a)

It is important to understand the characteristics of the biggest consumer groups (medium industry, large industry, and residential), as they together make up more than 85% of the CFE consumption. As seen in Table 7 the number of residential users roughly corresponds to the number of Mexican households, and their consumption per user is very low. On the other hand, approximately 1,000 companies are categorized as large industry, with each consuming on average 41 GWh per year. Assuming a constant energy consumption throughout the year, this would mean that on average all these users have a consumption above 4 MW, and are thus apt to become qualified users.

Table 7. Number of users and average electricity consumption per CFE user group (2015). Source: (SENER, 2015a).

	Users	GWh/user
Medium industry	310,404	0.262
Large industry	1,000	41.28
Residential	35,076,603	0.002
Commercial	3,881,213	0.004
Agriculture	127,603	0.079
Services	203,807	0.044

Even though in 2015 the largest share of electricity consumption was still satisfied by the CFE, consumption may also be satisfied by private generators, through modalities such as self-supply and co-generation, which provided almost 40,000 GWh of electricity in 2015 to the industrial sector (SENER, 2016a). These modalities have disappeared from the new *Law of the electricity sector,* as they have been incorporated into the term "*generator*". In 2015, the "*generator*" modality provided only 1,000 GWh to the wholesale electricity market.

4.2.4 THE ELECTRICITY MARKET

The newly created wholesale electricity market is operated by CENACE; in it, generators, distributors and qualified users may engage in commercial transactions (*Ley de la Industria Eléctrica*, 2014). Items which may be transacted include: electricity, capacity, clean energy certificates, ancillary services and financial services (*Ley de la Industria Eléctrica*, 2014). CENACE will calculate the final price for transactions based on the offers made by market participants [2]. Electricity and ancillary services dispatch is based on least marginal costs (SENER, 2015b).

Electricity pricing in the short-term market uses the "nodal pricing principle" (SENER, 2015c). This principle takes into consideration the transmission capacity of the grid as well as the transmission losses, and associates these prices to nodes, each corresponding to a transformer station in the transmission grid (International Energy Agency, 2005). Due to its transparency in the locational electricity transportation costs, it is expected to create incentives for investments in the transmission grid (International Energy Agency, 2005). However, there is concern about the distributional effects that this pricing principle may have across regions (International Energy Agency, 2005).

4.3 The climate policy

Having described the institutional framework and physical infrastructure which pertains to the electricity sector, it is possible to describe the climate policy in this context, and to map the existing policy instruments.

4.3.1 CLIMATE CHANGE MITIGATION LEGAL FRAMEWORK

The legal framework is described to allow for measuring the scope for action in terms of climate policy instrument development. As is described below, a solid legislative basis exists which permits either to establish effective emissions reduction instruments or to increase the ambition of existing ones.

General Law on Climate Change (LGCC)

As this law was approved in 2012, it made Mexico "the first developing country to have a comprehensive law on this topic (of climate change)" (Mexican Government, 2015). It sets the institutional and legal framework as well as the financial instruments for the climate change mitigation and adaptation efforts (*Ley General de Cambio Climático*, 2012). It gives the Federal government the faculty of establishing and designing the necessary "*economic, fiscal, financial and market instruments*" for climate change mitigation (*Ley General de Cambio Climático*, 2012). In particular, it gives the Ministry of Environment and Natural Resources

(SEMARNAT) the faculty of establishing a *voluntary* emissions trading scheme (*Ley General de Cambio Climático*, 2012).

The law establishes the National Institute for Ecology and Climate Change (INECC), which shall perform the national GHG emissions inventory according to the methodologies developed by the Intergovernmental Panel on Climate Change (IPCC)[11] (*Ley General de Cambio Climático*, 2012). According to the rules of the LGCC on greenhouse gas (GHG) emissions registry, entities from the energy, transport, industrial, agricultural, waste, and commercial/services sectors are liable to GHG emissions reporting if their total emissions are above 25,000 tCO_{2eq} (*Reglamento de la Ley General de Cambio Climático en Materia del Registro Nacional de Emisiones*, 2014). These entities are obliged to have an internal registry of their emissions since 2015[12] (*Reglamento de la Ley General de Cambio Climático en Materia del Registro Nacional de Emisiones*, 2014). According to the rules, GHG emissions include CO_2, CH_4, N_2O, black carbon, CFCs, HFCs, PFCs[13] and other compounds (*Reglamento de la Ley General de Cambio Climático en Materia del Registro Nacional de Emisiones*, 2014).

A transitory article indicates a goal to reduce GHG emissions by 30% in 2020 with respect to a business-as-usual (BAU) baseline[14], and by 50% in 2050 with respect to 2000 emissions[15], conditioned to international technological and financial support (*Ley General de Cambio Climático*, 2012). This goal is confirmed in the National Climate Change Strategy (ENCC) published in 2013 (SEMARNAT, 2013).

Intended Nationally Determined Contribution (INDC)

The voluntary commitment submitted by Mexico at the Conference of the Parties COP21 in Paris, France, in 2015, encompasses both climate change mitigation and adaptation, and both unconditional and conditional measures (Mexican Government, 2015). The approach to climate change mitigation includes the reduction of greenhouse gases and short-lived climate pollutants –mainly black carbon–, the latter particularly out of concern about local air quality (Mexican Government, 2015).

Mexico pledges to unconditionally reduce GHG emissions by 22% and black carbon emissions by 51% for 2030, with respect to a BAU baseline[16], and increase this to 36% and 70% respectively, conditional to a global agreement and international support (Mexican Government, 2015). The conditional reduction is aligned with the indicative goal for 2050 stated in the LGCC.

Other legislation

The *Law of the Energy Transition* regulates the use of sustainable energy, as well as emissions reduction in the electricity sector. In particular, it sets a goal of electricity generation by clean sources[17] of 25% by 2018, 30% by 2021, and 35% by 2024 (*Ley de Transición Energética*, 2015). The *Law of the Electricity Sector* establishes the obligation of the electricity sector to participate in the market-based mechanisms for emissions reduction which SEMARNAT decides upon (*Ley de la Industria Eléctrica*, 2014).

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[11] GHG emissions inventory originating from the combustion of fossil fuels shall be performed annually (*Ley General de Cambio Climático*, 2012).

[12] However, the transitory articles in the regulation determine that only entities with annual emissions above 1,000,000 tCO_{2eq} will officially report them for the year 2016, while entities with emissions between 100,000 and 999,999 tCO_{2eq} will report for the first time their emissions for 2017, and those entities with annual emissions between 25,000 and 100,000 tCO_{2eq} will report for the first time their emissions for the year 2018 (*Reglamento de la Ley General de Cambio Climático en Materia del Registro Nacional de Emisiones*, 2014).

[13] Clorofluorocarbons, hydrofluorocarbons, perfluorocarbons.

[14] The BAU baseline assumes no mitigation actions, which would correspond to 960 Mt_{CO2eq} in 2020, 1,276 $MtCO_{2eq}$ in 2030 and 2,257 $MtCO_{2eq}$ in 2050 (SEMARNAT, 2013). It is likely that this baseline includes black carbon emissions, a short-lived climate pollutant which Mexico reports separately in its national inventory.

[15] This means that by 2050 total emissions should be 320 $MtCO_{2eq}$ (SEMARNAT, 2013).

[16] BAU baseline is: 792 $MtCO_{2eq}$ of GHG and 114 $MtCO_{2eq}$ of BC in 2020; 888 $MtCO_{2eq}$ of GHG and 125 $MtCO_{2eq}$ of BC in 2025; 973 $MtCO_{2eq}$ of GHG and 137 $MtCO_{2eq}$ of BC in 2030 (Mexican Government, 2015).

[17] "Clean" electricity generation as defined by the Law of the Electricity Sector includes renewable sources (wind, solar, wave, geothermal, bioenergy, waste, hydropower), but also nuclear power and fossil-fuel powered power plants with carbon capture and storage technologies (*Ley de la Industria Eléctrica*, 2014).

4.3.2 INSTRUMENTS FOR CLIMATE CHANGE MITIGATION

As will be described below, timid attempts at establishing a carbon tax and an ETS are already underway. Understanding their current design is important to guide the policy-recommendations which will be presented as a conclusion of this thesis.

Law of Special Tax on Products and Services (IEPS)

The IEPS came into effect in 1980 (*Ley del Impuesto Especial sobre Producción y Servicios*, 2016), but it wasn't until amendments performed in 2013 that the carbon contents of fuels were levied (SHCP, 2013), effectively constituting the first carbon tax. Further amendments in 2014 and 2016 increased the value of this tax (SHCP, 2016, 2014). The originally suggested value for the carbon tax was 70 pesos/tCO_2 for all fuels[18]. This was equivalent to a tax of 5 USD/tCO_2 at the time of the proposal[19]. However, as can be seen in the Table 8, the actual level of the tax is at best 70% of the original price, and slightly higher than 10% of the original level for fuels with high carbon content. The value of the carbon tax for natural gas is zero.

The Mexican carbon tax is one of the lowest worldwide, close only to that in Japan, Poland and Latvia, while Portugal, Slovenia, France, Switzerland and Sweden have carbon taxes of 8, 20, 25, 88 and 127 USD/tCO_2 respectively (World Bank Group and ECOFYS, 2016). When the tax was first presented to Congress, the revenue generated was supposed to be directed towards climate change mitigation actions, such as energy efficiency, technology improvement and public transport ("Boletín N° 3710," 2014) (Congreso de la Unión, 2012). However, according to Mexican legislation, tax revenue must be directed to general funds and may not be ear-marked.

The IEPS tax on CO_2 may be paid in carbon *offsets* at the transaction date's market value (*Ley del Impuesto Especial sobre Producción y Servicios*, 2016). At the moment, carbon offsets are provided as part of the Clean Development Mechanism established in the Kyoto Protocol, and may include carbon allowances from a future emissions trading instrument (*Ley del Impuesto Especial sobre Producción y Servicios*, 2016).

Table 8. Carbon tax for different fossil fuels as set in the IEPS. Source: (SHCP, 2013), (SHCP, 2014), (SHCP, 2016) and (SEMARNAT, 2014).

Fossil fuels	Unit	Originally suggested values	DOF 11-01-2013	DOF 22-12-2014	DOF 27-12-2016	Carbon contents	Carbon tax (original) in pesos/tCO_2	Carbon tax (2016) in pesos/ tCO_2	%
Natural gas	cents/ m^3	11.94	0	0	0	0.526 kgC/m3	70	0.0	0%
Propane	cents/l	10.50	5.91	6.15	6.5	0.458 kgC/l	70	38.4	54%
Butane	cents/l	12.86	7.66	7.97	8.42	0.458 kgC/l	70	49.7	70%
Gasoline and jet fuel "gasavión"	cents/l	16.21	10.38	10.81	11.41	0.619 kgC/l	70	49.8	71%
Jetfuel and kerosenes	cents/l	18.71	12.40	12.91	13.64	0.71 kgC/l	70	51.9	73%
Diesel	cents/l	19.17	12.59	13.11	13.84	0.722 kgC/l	70	51.8	73%
Fuel oil	cents/l	20.74	13.45	14	14.78	0.813 kgC/l	70	49.1	70%
Petroleum coke	pesos/ton	189.85	15.60	16.24	17.15	0.9 kgC/kg	70	8.6	12%
Coal	pesos/ton	178.33	27.54	28.68	30.28	0.825 kgC/kg	70	9.9	14%

Emissions Trading Scheme (ETS)

The SEMARNAT and the Mexican Stock Exchange began an ETS simulation exercise in 2017 (MOU signed in august 2016) (SEMARNAT, 2016b). An ETS pilot program is set to begin in 2018, in parallel with the draft of ETS regulation (SEMARNAT, 2016b). It has been suggested that the simulation exercise

[18] 1 metric ton of carbon = 3.7 metric ton of CO_2 equivalent (US EPA, n.d.).

[19] With an exchange rate of 13.1 pesos/USD in 2012 (Banxico, n.d.).

will involve the voluntary participation of 70-120 entities from the most important sectors, and that the total duration will be of one year divided into periods of 2-3 months (MexiCO2, 2017).

Clean energy certificates (CELs)

The objective of this instrument is to promote renewable electricity generation. They are emitted by the regulatory commission. Qualified users and electricity suppliers are obliged to have a certain share of their generation by clean sources, and they can comply by buying clean energy certificates (CELs), which generates additional income to clean electricity generators ("Tracking the Progress of Mexico's Power Sector Reform," 2016). CELs will be traded in the wholesale electricity market starting in 2018 (CENACE, 2017). CELs may also be offered in the long-term auctions (SENER, 2015d).

Although this instrument doesn't directly tackle GHG emissions reduction, it does so indirectly, particularly when it relates to emissions from the electricity sector. A comprehensive discussion on climate policy impacting the electricity sector would not be complete without it. To clarify the relationship between these instruments, Figure 13 illustrates the point of regulation of each of the previously described instruments.

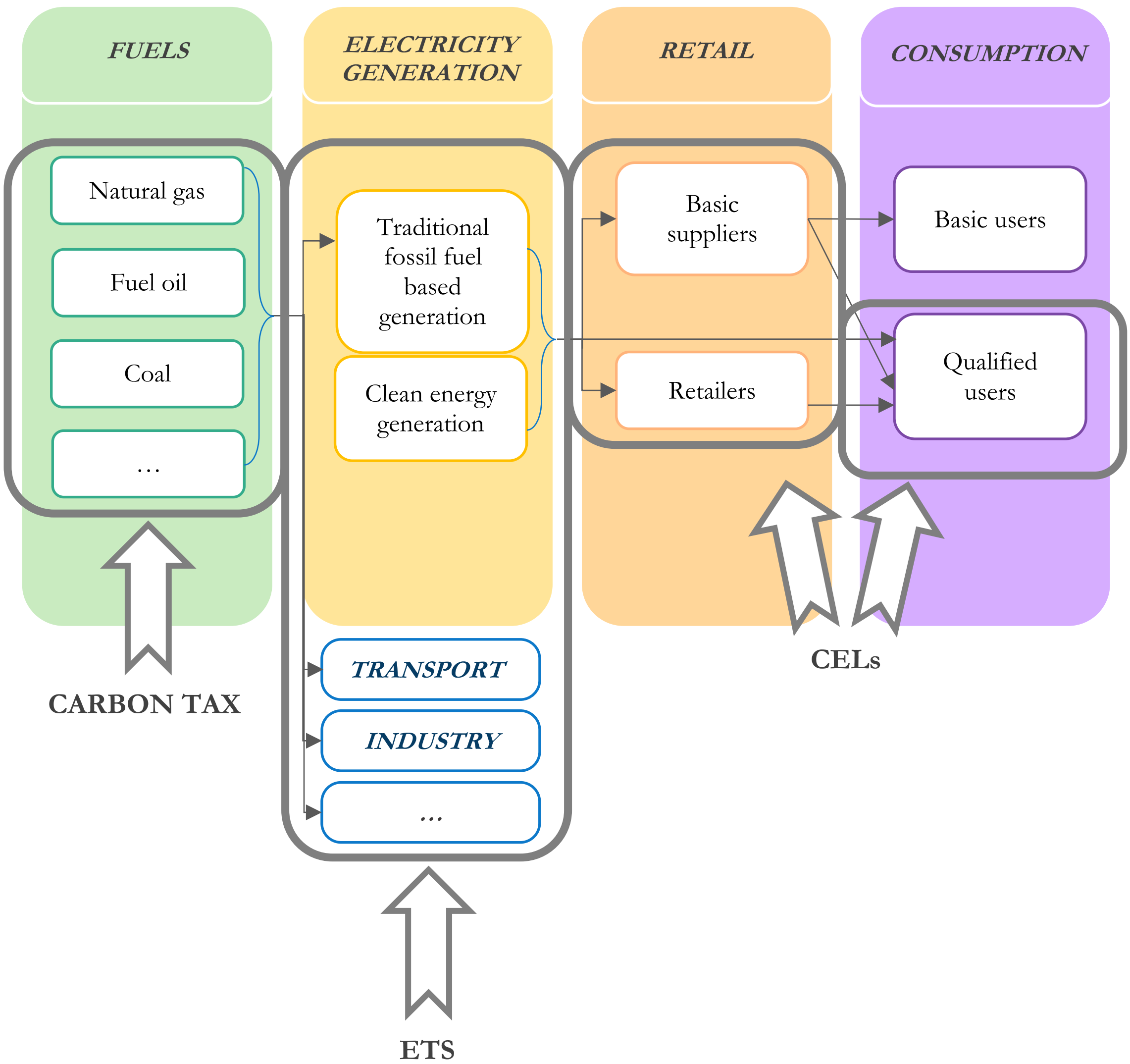


Figure 13. Policy instruments impacting the electricity sector and its GHG emissions performance.

5 Results

5.1 Modeling results

The results from the tax and cap scenario simulations are presented and analyzed in this section. First, the reference scenario is compared to the official electricity sector development plans, to confirm the relevance of the modeling assumptions. Then, the results of the simulations are presented, followed by those of the sensitivity analysis. Finally, the results are analyzed according to the economic effects' assessment criteria.

5.1.1 VALIDATION OF THE REFERENCE SCENARIO

The simulated REF scenario was compared with the 2016 and 2017 versions of the national electricity system development program (PRODESEN)[20]. The planning performed by the Ministry of Energy for the PRODESEN is also based on a model of the Mexican electricity system which optimizes total system costs. However, and as opposed to the Balmorel (which uses myopic foresight, see Section 3.1.1), it operates under the premise of perfect foresight: it minimizes the net present value of the costs[21] for the whole modeling period.

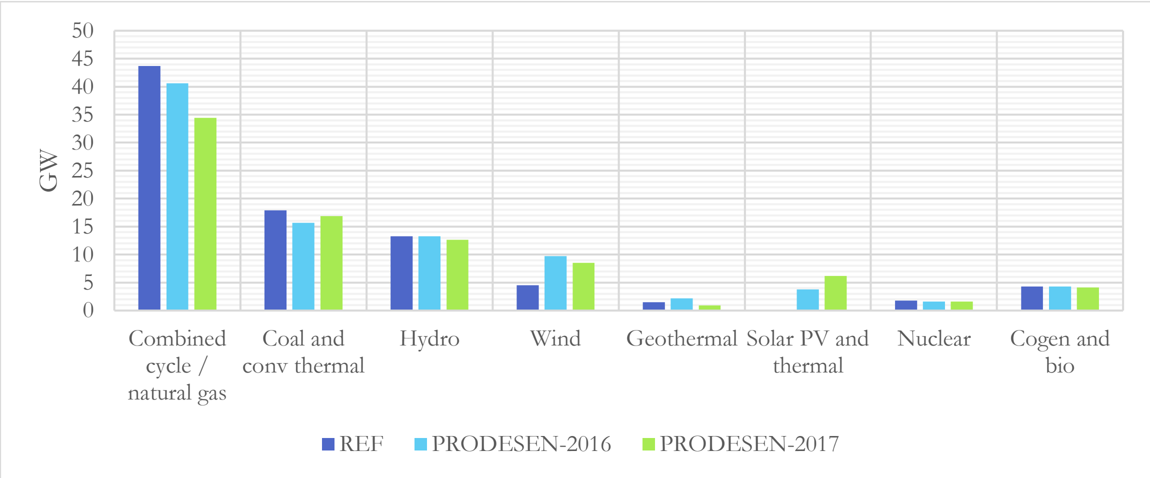


Figure 14. Installed capacity by technology in year 2021, for the REF scenario and the PRODESEN 2016 and 2017. Source: Balmorel modeling, (SENER, 2016a) and (SENER, 2017).

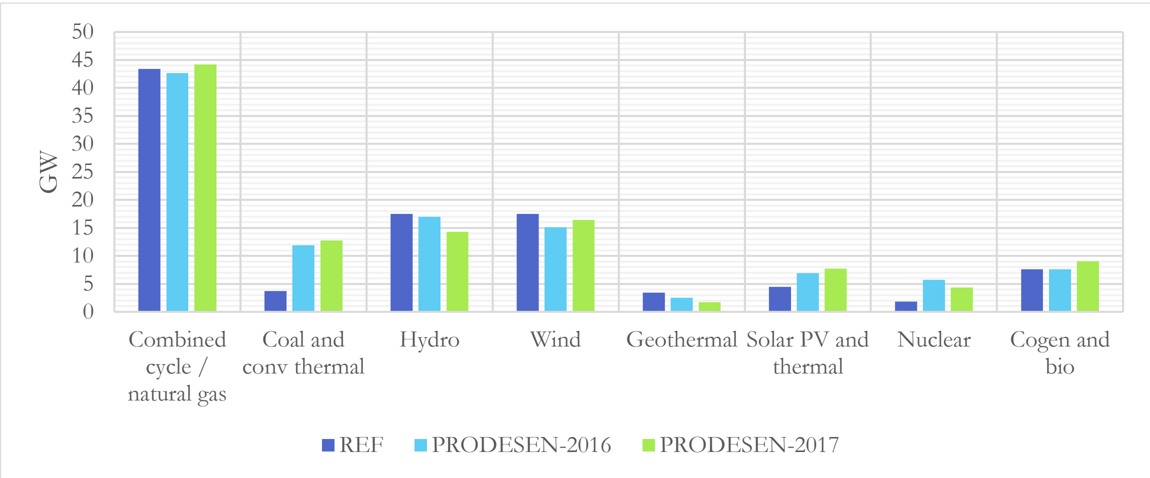


Figure 15. Installed capacity by technology in year 2030, for the REF scenario and the PRODESEN 2016 and 2017. Source: Balmorel modeling, (SENER, 2016a) and (SENER, 2017).

[20] The 2017 version was published during the initial stages of the simulation process.
[21] All costs are annualized using the discount rate.

Snapshots from 2021 and 2030 were compared between the REF scenario and the two PRODESEN. The installed capacity by technology for each scenario is shown in Figure 14 and Figure 15, while the electricity generation by technology is shown in Figure 16 and Figure 17. It should be noted that Balmorel results are presented in terms of fuel (i.e. natural gas, coal, fuel oil, etc.) while the PRODESEN plans categorize by generation technology[22].

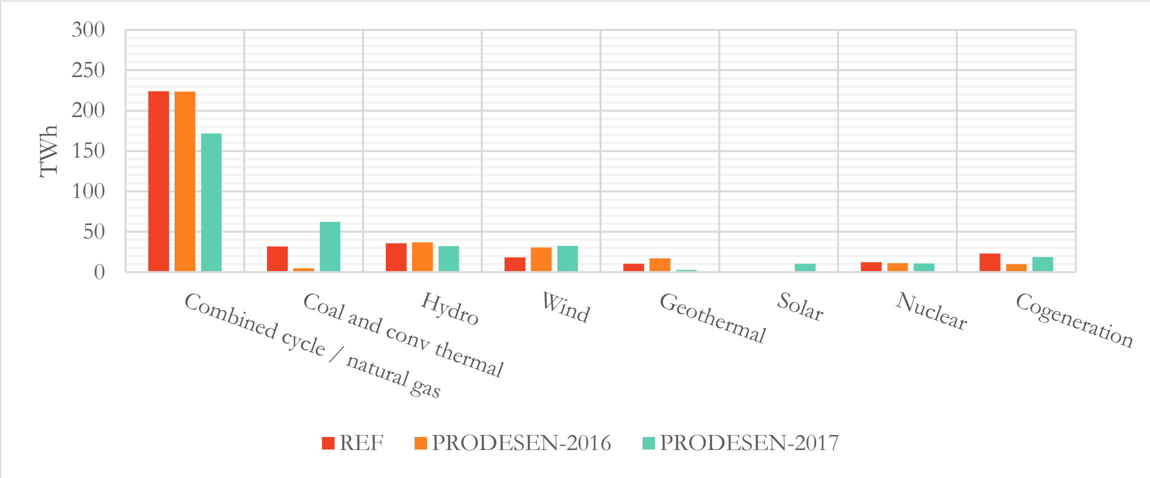


Figure 16. Electricity generation by technology in year 2021, for the REF scenario and the PRODESEN 2016 and 2017. Source: Balmorel modeling, (SENER, 2016a) and (SENER, 2017)

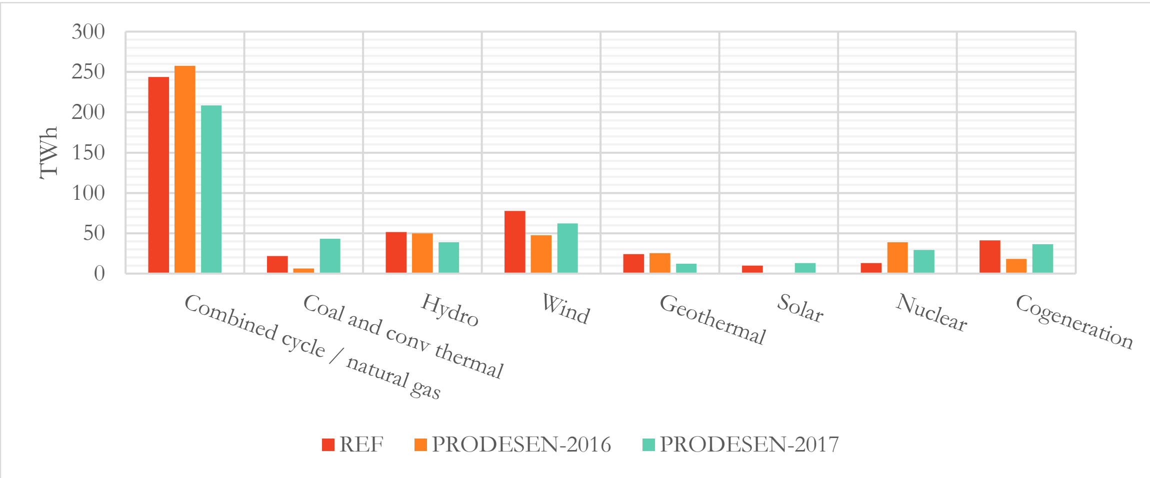


Figure 17. Electricity generation by technology in year 2030, for the REF scenario and the PRODESEN 2016 and 2017. Source: Balmorel modeling, (SENER, 2016a) and (SENER, 2017).

There are few significant differences between the REF scenario and the PRODESEN with regards to the future energy matrix. The REF scenario has a much lower coal and conventional thermal generation installed capacity than both PRODESEN plans. Also, electricity generation by such technology is lower in the REF scenario than the PRODESEN 2017, instead having a higher wind and hydro power generation. This might suggest that the GHG emissions calculated in the Balmorel model are underestimated. Another possibility is that the difference is due to the technology categorization; when adding up the *combined cycle* and *coal and conventional thermal* categories, the difference between the official plans and the REF scenario is only around 10%.

Finally, the cost structure for the REF scenario and the PRODESEN 2017 is compared in Table 9. Due to the contrasting modeling approaches, the cost structure differs greatly. The Balmorel REF scenario has high and annually increasing operational costs, while in the PRODESEN 2017 these costs are low and

[22] The category *combined cycle/natural gas* shown in Figure 16 and Figure 17 combines the *combined cycle* results from PRODESEN with the *natural gas* results from Balmorel. Still, they are not entirely equivalent, since not all natural gas generation from the REF scenario results must necessarily correspond to combined cycle generation.

annually decreasing[23]. The situation is reversed for the capital costs. Such a behavior is expected as in the PRODESEN all costs are annualized using a discount rate, while Balmorel only annualizes investment costs. Overall, the results of the REF and the latest PRODESEN regarding the future electricity system are similar, and the Balmorel model can be validated.

Table 9. System costs for the REF scenario and the PRODESEN 2017, in million USD. Source: Balmorel and (SENER, 2017).

	Balmorel REF Scenario					PRODESEN 2017				
	Capital Cost[24]	Fixed O&M	Variable O&M	Fuel Cost	Total	Capital Cost	Fixed O&M	Variable O&M	Fuel Cost	Total
2018	139	6,198	979	7,939	15,394	2,112	1,503	698	5,506	9,819
2021	139	6,392	1,135	9,719	17,524	3,177	1,223	588	4,382	9,370
2024	369	6,665	1,198	10,460	19,062	3,054	974	482	3,698	8,208
2027	1,000	7,004	1,200	10,697	20,900	2,801	782	392	3,250	7,225
2030	1,460	6,735	1,139	11,777	22,571	33,203	7,437	3,511	28,596	72,747

5.1.2 SCENARIO RESULT ANALYSIS

The first finding is that the non-conditional emission reduction target of the INDCs does not represent a constraint. The REF scenario is already below the target (except in 2018), as is the CAPL scenario. The high-ambition cap CAPH scenario, which follows the conditional target, does present a constraint on emissions. By 2030, the existing tax TAXE would reduce emissions by 7% compared to the REF scenario, while the TAXM would reduce by 25% and TAXH by 55%. Figure 18 shows the annual GHG emissions for each of the scenarios, and it can be observed that most scenarios have a downward peak in emissions in 2027. A possible explanation for this behavior is that as renewable energy costs decrease and fossil fuel prices increase, carbon-intensive generation decreases with a resulting decline in emissions until 2027; however, by 2030 the electricity demand grows more than can be compensated by the decreasing renewable costs/increasing fossil fuel prices.

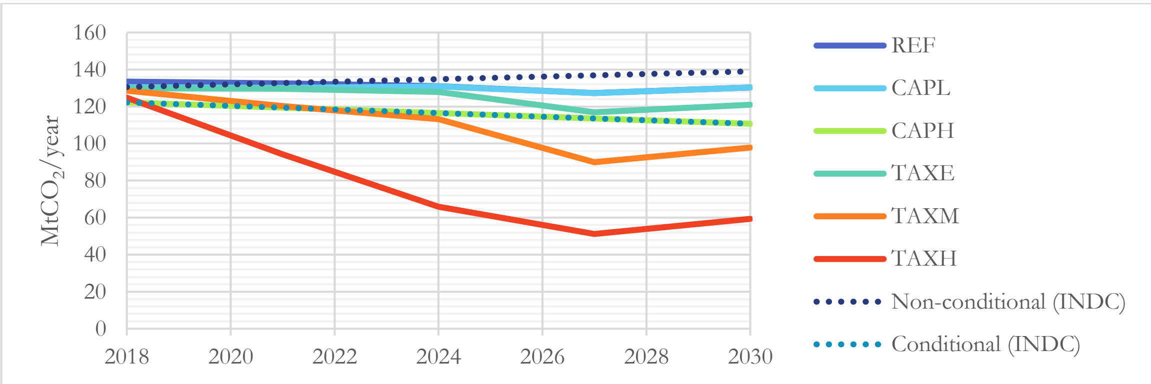


Figure 18. GHG emissions from the Mexican power sector[25] (2018-2030), by scenario.

As mentioned in Section 2.1.2., both a carbon tax and an ETS put a price on carbon, either directly or indirectly. The price is straightforward for a tax, as it simply corresponds to the tax rate. For an ETS, it is determined as the *shadow price* or marginal price which results from the constraint imposed by the cap on GHG emission: it is the change in the value of the objective function when relaxing the constraint by one unit of emission (tCO_2). Figure 19 allows to compare the modelled tax levels with the equilibrium emission permit price which would be established in an ETS. Despite the observed depression in 2027 explained above, the medium level of tax (TAXM) is closest to the high ambition cap (CAPH) emission permit price.

[23] With the exception of year 2030, an issue which is not within the scope of this research.
[24] To account for the modeling being done only every third year (see Section 3.1.3), Balmorel capital costs results have been divided by three to be directly comparable to the results from PRODESEN, which models all years.
[25] Assuming 100% of the emissions associated with co-generation plants are allocated to the electricity sector.

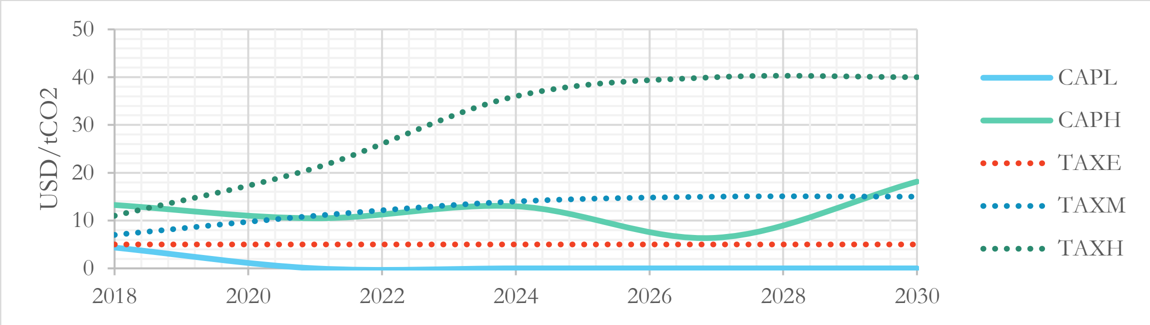


Figure 19. Tax level or emission permit price, by scenario.

Although it has been hinted that the CAPH and TAXM could be equivalent in terms of their price on carbon, the behavior on low-carbon installed capacity differs. As observed in Figure 20, the CAPH and TAXM scenarios have a practically identical installed capacity until 2024. However, following the emission permit price decrease in 2027, the wind and solar installed capacity of the CAPH scenario stays significantly lower than that of TAXM in the subsequent years, despite the emission permit price recovery in 2030. The total installed capacity decreases from 2027 to 2030 because of programmed decommissions (exogenous to the model), stated in the PRODESEN 2016. As shown in Figure 21Figure 21. Electricity generation by technology (2018-2030), for the CAPH and TAXM scenarios., the result is more wind and solar generation in the TAXM scenario, as opposed to a higher natural gas-based generation in the CAPH scenario.

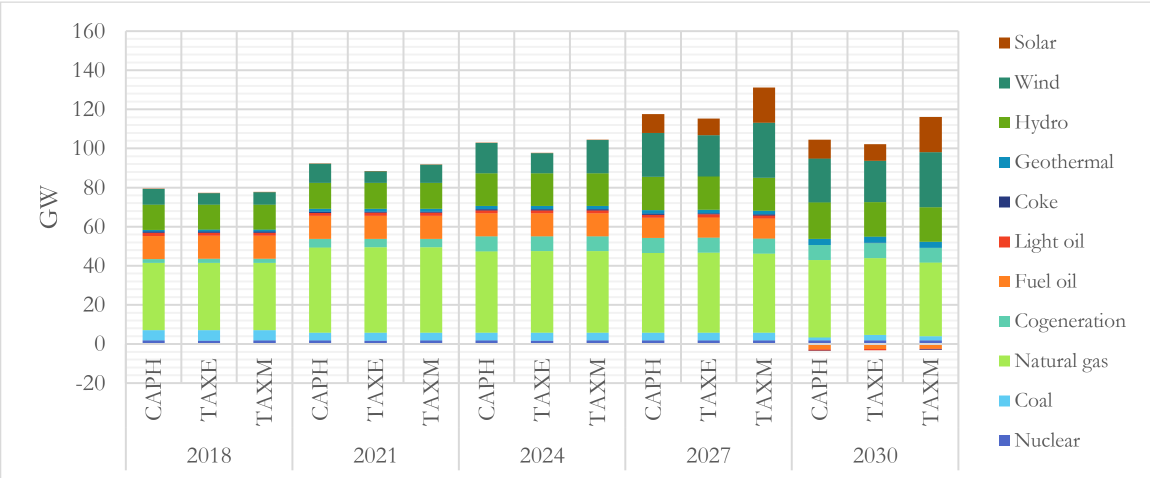


Figure 20. Installed capacity by technology (2018-2030), for the CAPH, TAXE and TAXM scenarios.

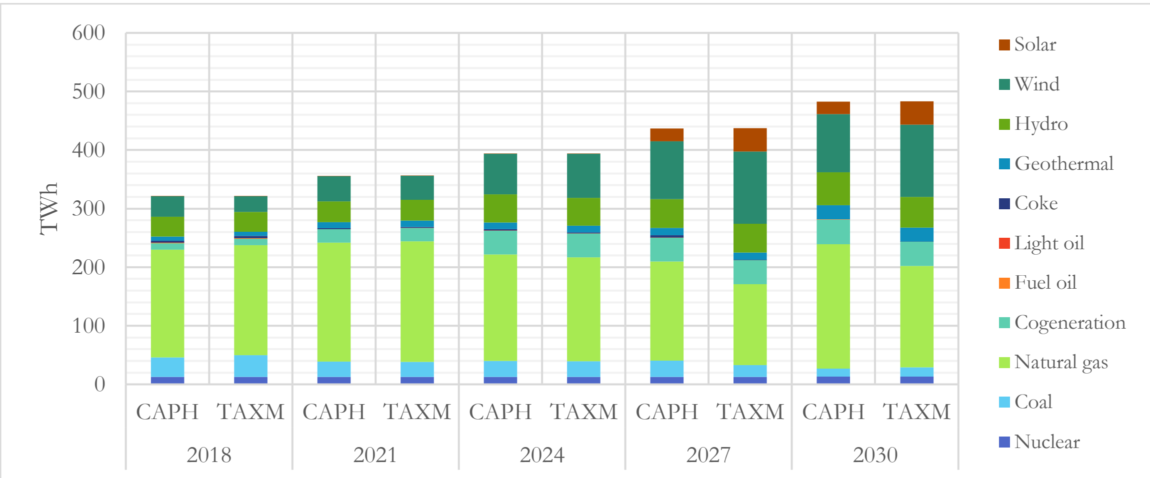


Figure 21. Electricity generation by technology (2018-2030), for the CAPH and TAXM scenarios.

The clean energy goals stated in the *Law of Energy Transition* are shown along with the shares of generation of different scenarios in Figure 22. The REF, CAPL and TAXE scenarios are unable to reach the target in 2021; in the rest of the scenarios the share of clean energy generation is well above the target[26]. Non-renewable clean energy corresponds to nuclear and cogeneration; all increases in non-renewable clean energy come from cogeneration, as none of the scenarios invest in nuclear capacity.

Renewable generation increases in all scenarios, albeit at a different growth rate. Even in the REF scenario, the increase in intermittent renewables (mainly wind) increasingly requires dispatchable, load-following generation, such as that provided by combined cycle and hydropower technologies. This situation can be observed when comparing Figure 23 and Figure 24. The figures show the supply and demand load curves of 4 weeks, each representing a different season (where *s* stands for the week within the year, and *t* stands for the hour within the week).

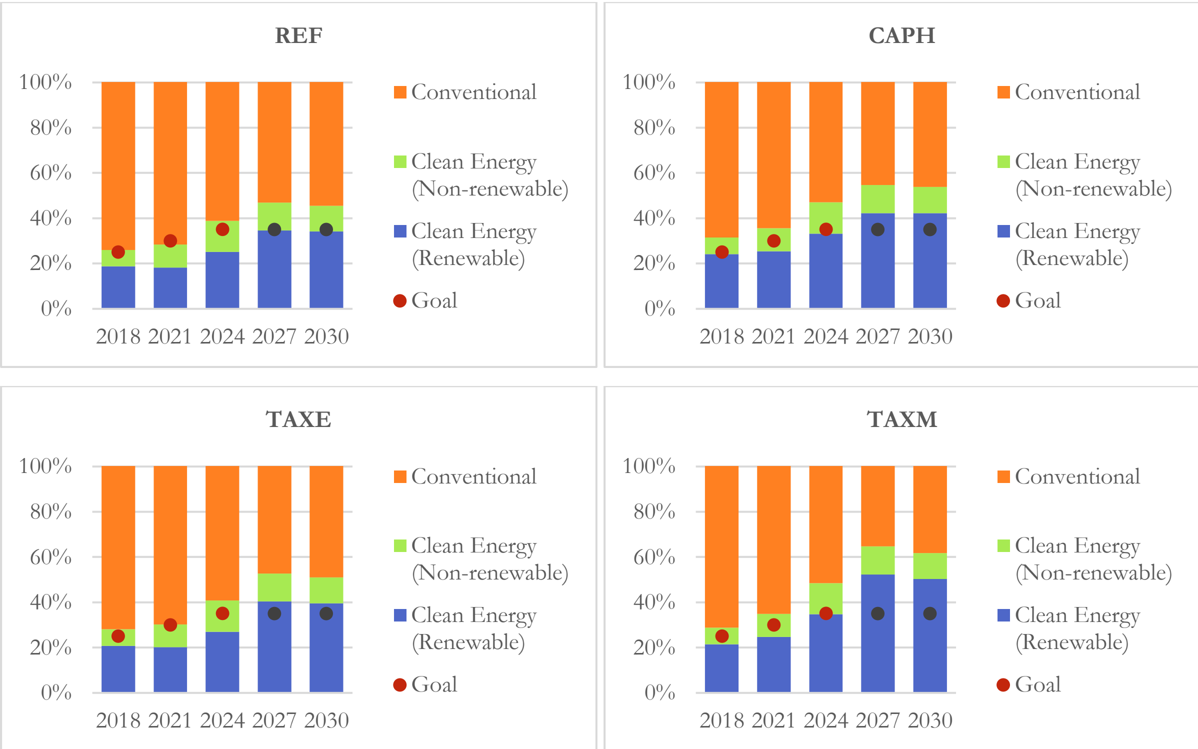


Figure 22. Shares of clean energy generation (2018-2030) for the REF, CAPH, TAXE and TAXM scenarios.

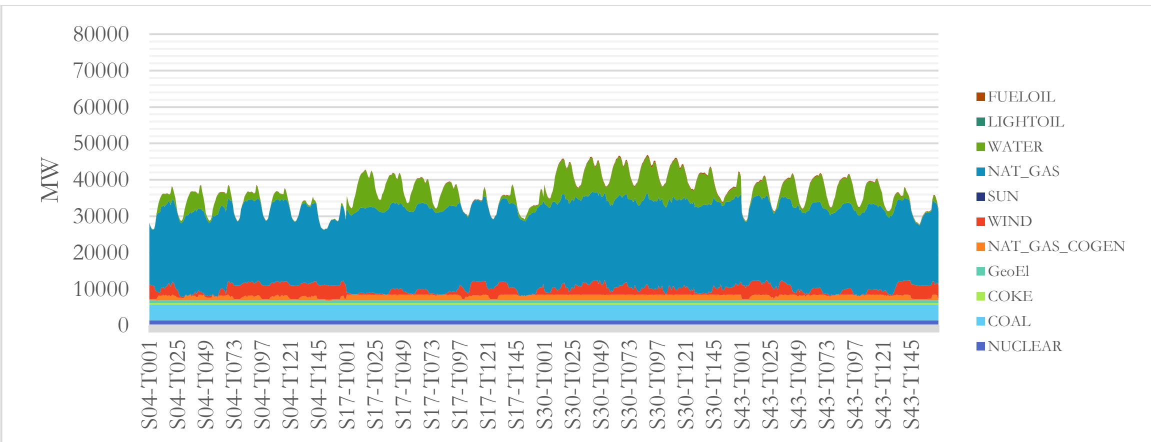


Figure 23. Supply and demand load curve for four representative weeks, for the REF scenario (2018).

26 The target for years 2027 and 2030 is unknown, so it has been kept constant at the level of 2024.

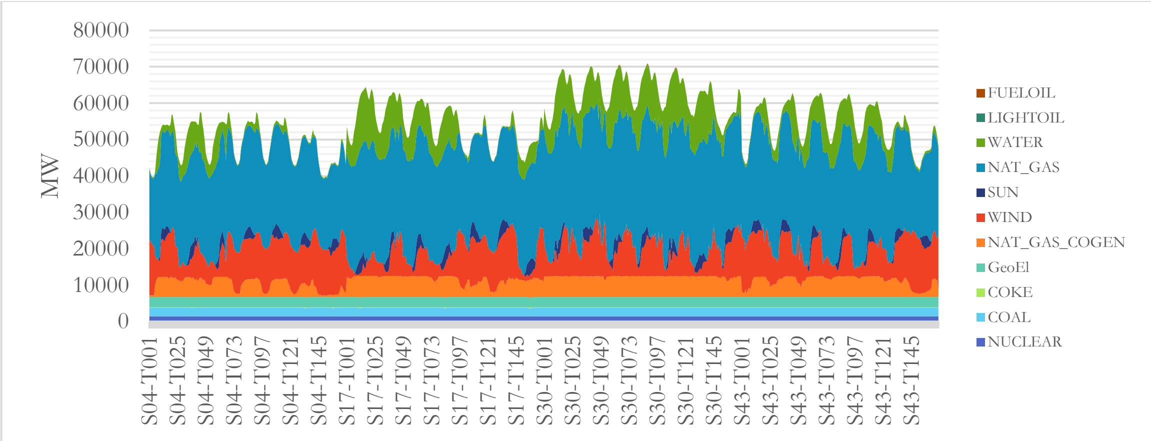


Figure 24. Supply and demand load curve for four representative weeks, for the REF scenario (2030).

The need for load-following generation becomes more drastic in those scenarios which are more ambitious in terms of emissions restrictions, because they install more intermittent renewable generation, as can be observed in Figure 25.

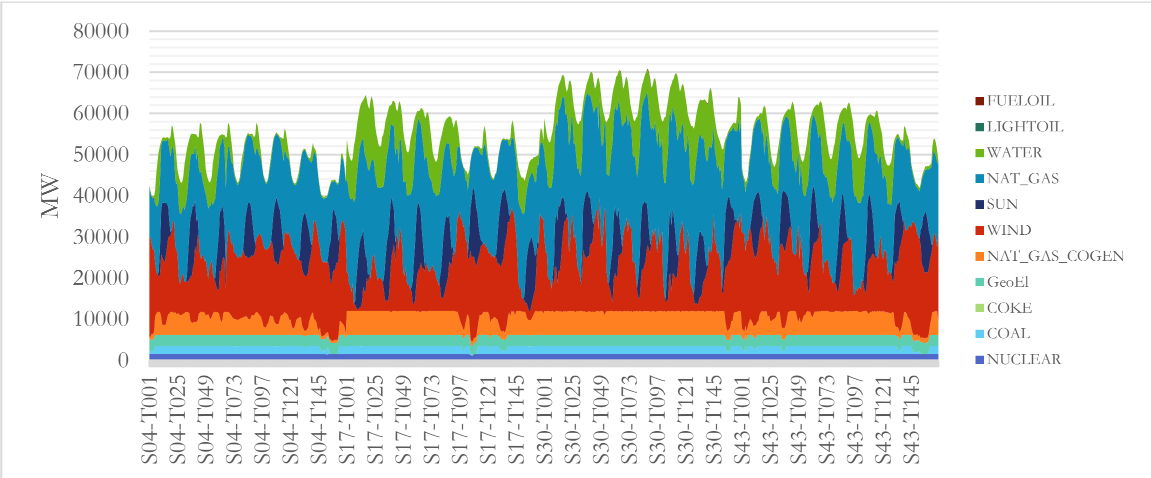


Figure 25. Supply and demand load curve for four representative weeks, for the TAXM scenario (2030).

The scenarios that penalize carbon generation the most are, in decreasing order of constraint, TAXH, TAXM and CAPH. Another consequence of these constraints is that the higher investment in intermittent renewable generation requires the strongest investments in transmission infrastructure, as can be observed below in Figure 26.

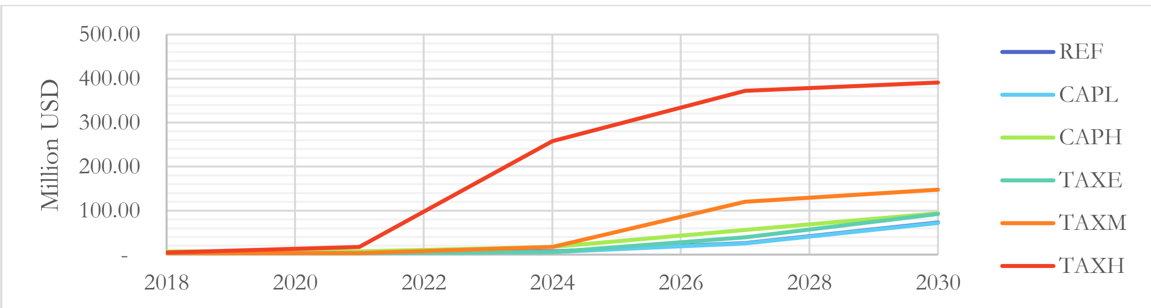


Figure 26. Annualized investments in electricity transmission (2018-2030) for the different scenarios.

However, total system costs (annualized) of all scenarios differ from the REF scenario by less than 1%, except for the TAXH scenario whose system costs are 5% higher than those of the REF scenario. The increasing capital costs incurred in by the scenarios which invest more in renewable generation, are compensated by decreasing fuel costs, as can be seen in the Figures below.

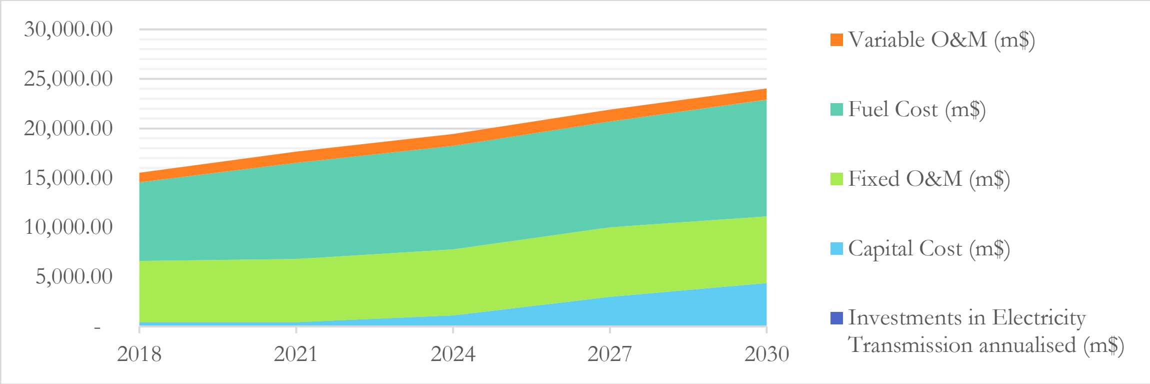


Figure 27. Annualized total system costs (2018-2030) for the REF scenario, in million USD.

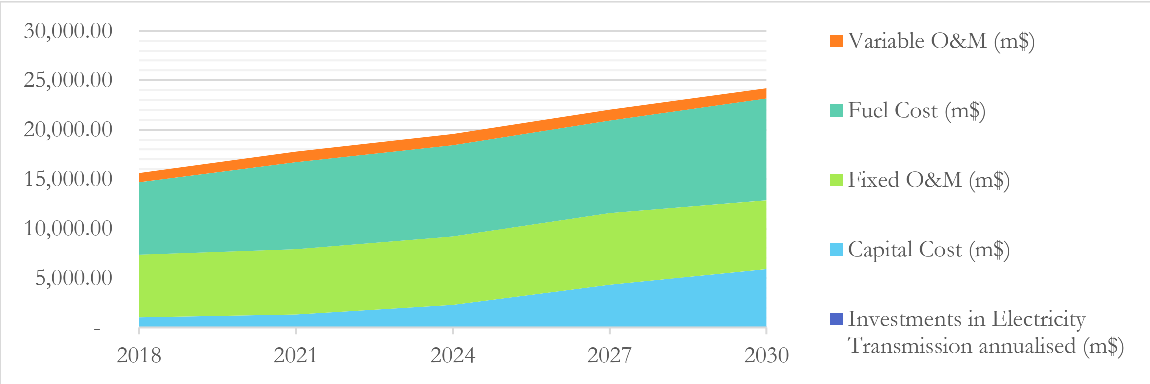


Figure 28. Annualized total system costs (2018-2030) for the CAPH scenario, in million USD.

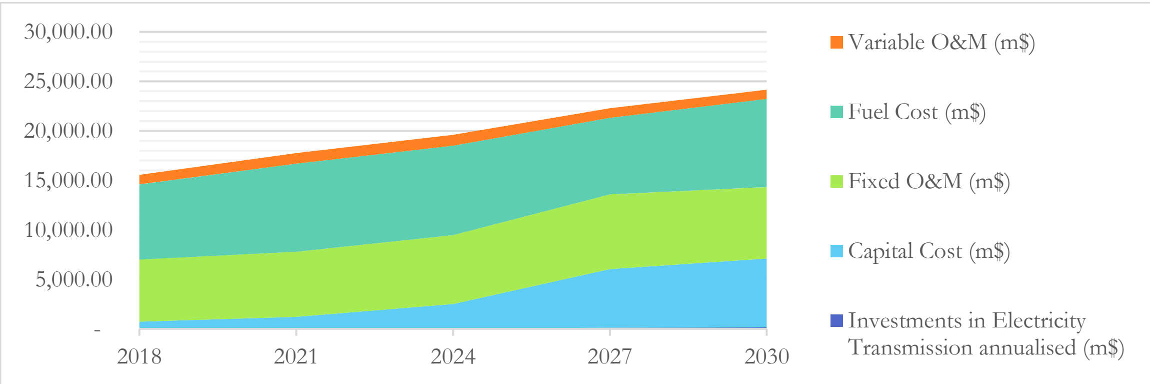


Figure 29. Annualized total system costs (2018-2030) for the TAXM scenario, in million USD.

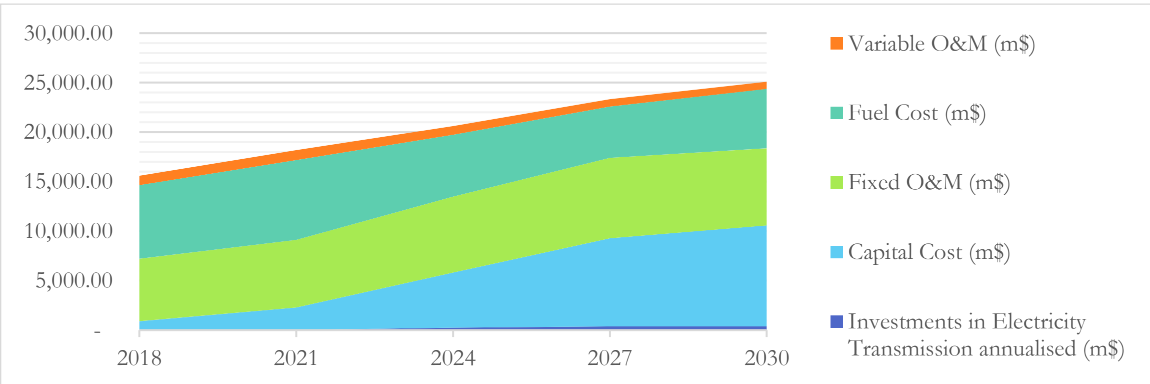


Figure 30. Annualized total system costs (2018-2030) for the TAXH scenario, in million USD.

The electricity price in Balmorel is calculated as the *shadow price* of the electricity balance constraint: it is the change in the value of the objective function when relaxing the constraint by one unit of electricity generation (MWh). Because the objective function contains the capital cost terms, the calculated electricity price shown in Figure 31 is the *long-run marginal cost* (as opposed to the *short-run marginal cost* used in the electricity markets, which only covers operational costs). Using this method to calculate average electricity prices is relevant for Mexico, since it has established a capacity market which makes it likely that investment costs will be covered by electricity consumers.

As increasing fossil fuel prices raises operational costs and a growing electricity demand requires new capacity investments, the average electricity prices increases for all scenarios throughout the modeling period. Variation among scenarios is a consequence of the carbon-pricing mechanisms: they affect the operational costs and encourage new low-carbon investments, which in turn increases capital costs and the overall electricity price. As can be observed in Figure 31, the TAXM and CAPH scenarios have similar pricing behaviors. The increase in electricity price from one scenario to another is not necessarily homogeneous across regions: from the TAXM to TAXH scenario, some regions see a price increase of 3USD/MWh while others increase 6 USD/MWh, as can be observed by comparing Figure 32 and Figure 33. This is probably a consequence of insufficient transmission infrastructure.

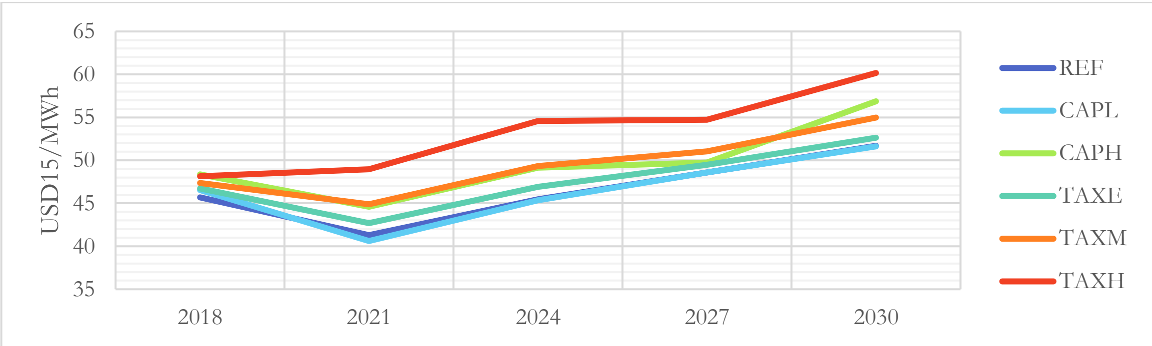


Figure 31. Average electricity prices (2018-2030) for the different tax and cap scenarios.

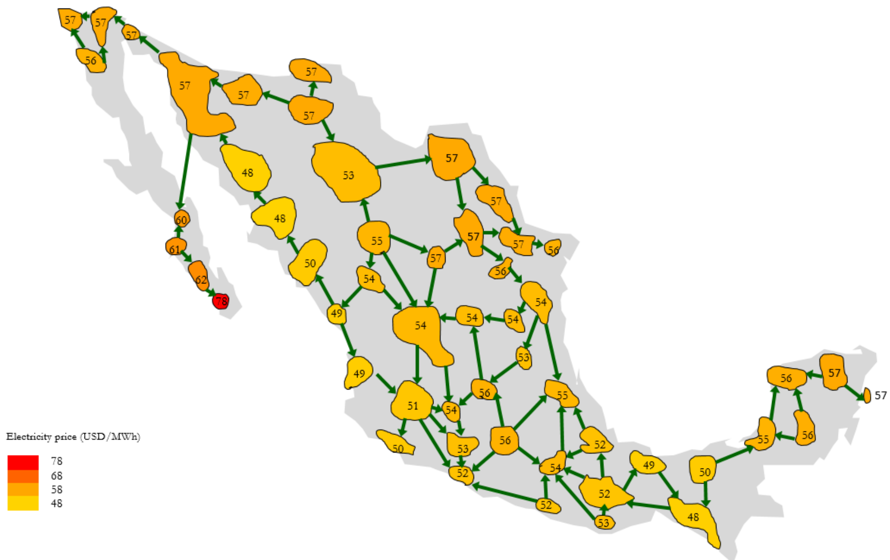


Figure 32. Average electricity prices for year 2030, per region. TAXM scenario.

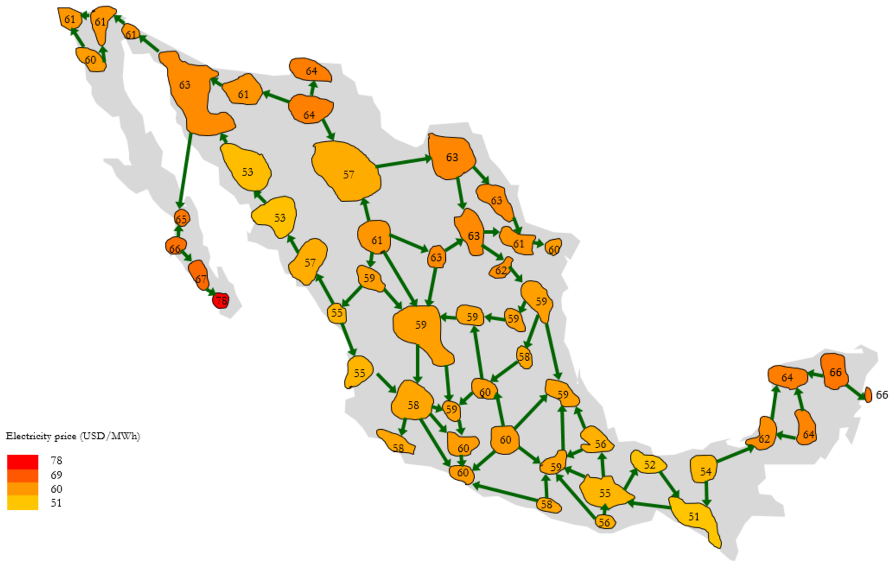


Figure 33. Average electricity prices for year 2030, per region. TAXH scenario

An additional scenario with a zero-level tax rate on natural gas was simulated (TAXM_NG-NoTax), to explore what would happen if the present exemption on natural gas was maintained. Such situation would indeed favor natural gas over coal, as can be observed in Figure 34. The overall picture, however, is less bright. Emissions from natural gas generation would be exactly the same as the REF (no policy) scenario, and 40% higher than in the wide-coverage TAXM scenario. Total emissions would be 17% higher than the TAXM scenario.

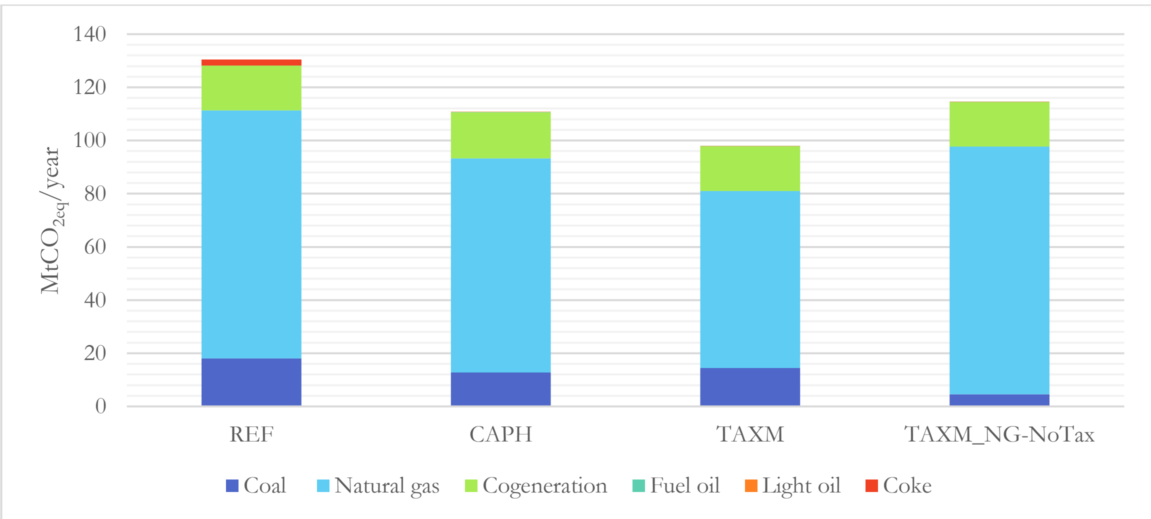


Figure 34. GHG emissions in year 2030, for the REF, CAPH and TAXM scenarios, and a comparison with a zero-level tax on natural gas.

In terms of installed capacity, a zero-level tax rate for natural gas would generate no change whatsoever in the natural gas installed capacity compared to the REF scenario, while it would generate a 14% higher natural gas capacity compared to the TAXM scenario (see Figure 35). The solar and wind installed capacity would be 57% and 31% lower, respectively, than in the TAXM scenario. Due to the insufficient signal caused by the exemption of natural gas from the tax, the renewable energy generation targets would not be met in year 2021, as seen in Figure 36. Although the cost pattern would differ to that of the TAXM scenario, as shown in Figure 37, the total system annualized costs would be the same. The average electricity price would be approximately 5% lower than the CAPH and TAXM scenarios, throughout the whole 2018-2030 period.

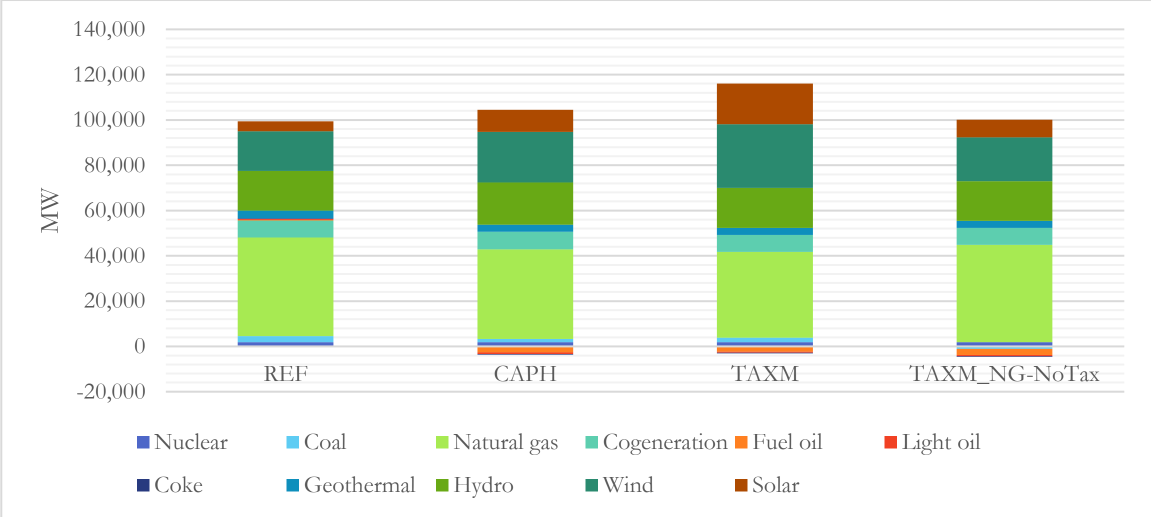


Figure 35. Installed capacity in year 2030, for the REF, CAPH and TAXM scenarios, and a comparison with a zero-level tax on natural gas.

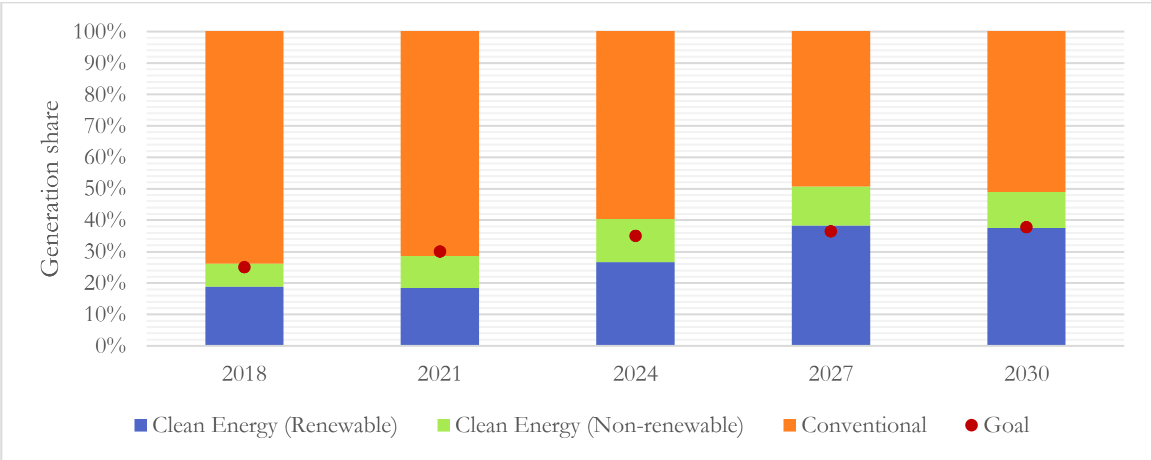


Figure 36. Clean Energy generation shares for the TAXM with zero-level rate on natural gas scenario.

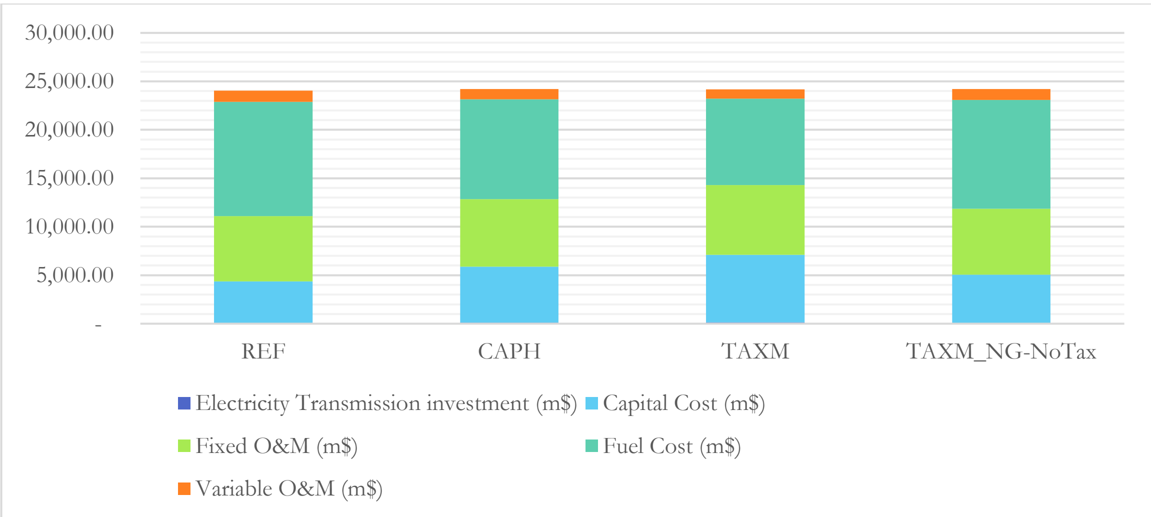


Figure 37. Annualized total system costs for the REF, CAPH and TAXM scenarios, and a comparison with a zero-level tax rate on natural gas, in million USD.

5.1.3 Sensitivity analysis

A sensitivity analysis was performed for the CAPH and TAXM scenarios to account for the uncertainty in the original assumptions. The reasoning behind the parameter selection is explained in Section 3.1.3.

Uncertainty in electricity demand

Emissions remain unchanged for the CAPH scenario even when assuming an electricity demand 10% lower (EDLow in Figures below) than in the base CAPH scenario. This means that the conditional cap represents a constraint even in such situation, resulting in a non-zero value for the emission permit price throughout the whole period, as reflected in Figure 39. System emissions are more vulnerable to changes in electricity demand in the TAXM scenario; an electricity demand 10% higher (EDHigh) than projected would cause emissions to be on average 9% above the conditional target. However, a CAPH scenario with 10% higher electricity demand would result in a carbon-price which is on average 26% higher than in the base CAPH scenario.

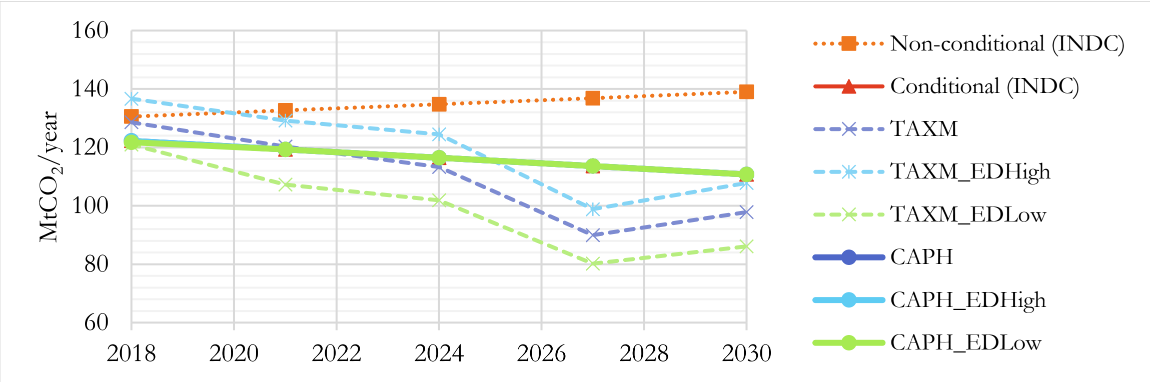


Figure 38. GHG emissions (2018-2030) for TAXM and CAPH scenarios with +/-10% projected electricity demand.

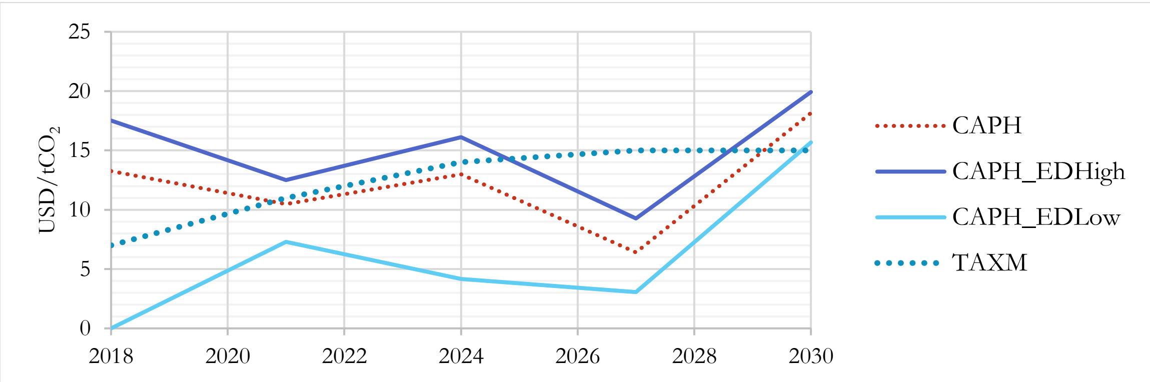


Figure 39. TAXM and emission permit price for the CAPH scenario with +/- 10% projected electricity demand.

Due to the limit on emissions in the CAPH scenario, even in a +10% electricity demand situation almost no additional fossil-fuel based generation capacity would be installed (compared with normal demand CAPH). The increase in installed capacity would come from intermittent renewables, solar being the favored technology. The behavior of conventional generation capacity installation under varying electricity demand is similar for the TAXM and CAPH scenarios. However, because a TAXM maintains a stable price signal (see Figure 39), more renewable generation capacity would be installed throughout the period.

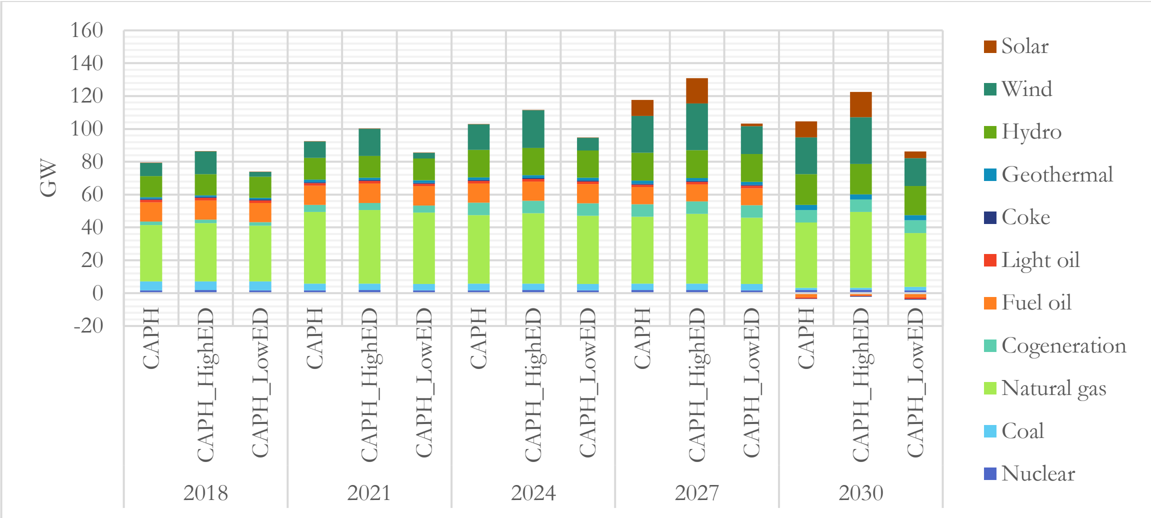


Figure 40. Installed capacity by technology (2018-2030), for the CAPH scenario with +/- 10% projected electricity demand.

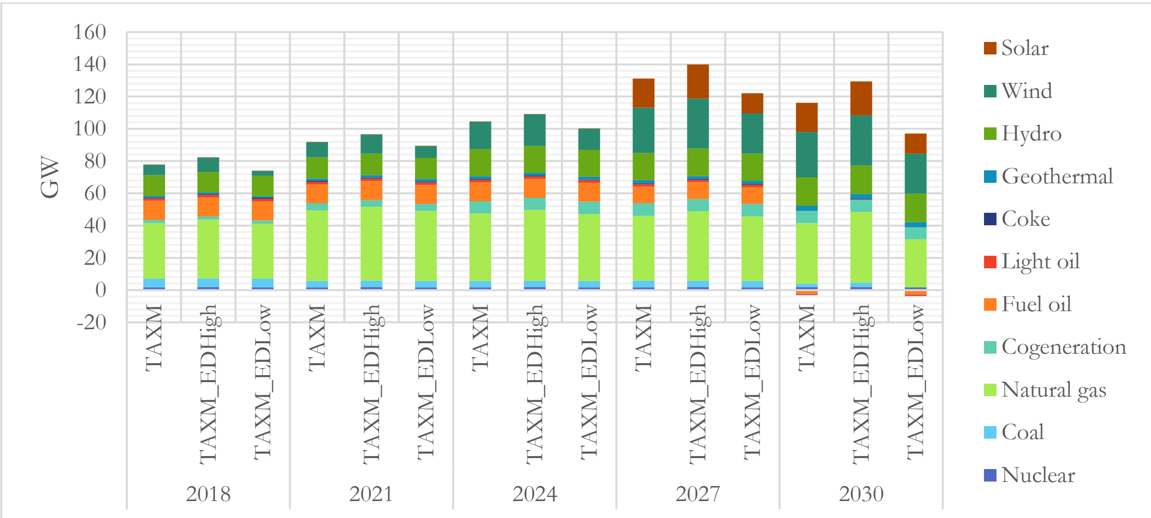


Figure 41. Installed capacity by technology (2018-2030), for the TAXM scenario with +/- 10% projected electricity demand.

Uncertainty in fuel prices

A variation of +/-10% in projected fossil fuel prices would cause important changes in emissions relative to the TAXM scenario, but practically no alterations for the CAPH scenario. If fossil fuel prices were lower (FPLow) than currently predicted in the TAXM scenario, emissions would be above the cap in 2018 and 2021, and fall below the non-conditional INDC target in 2024. On the other hand, high fossil fuel prices (FPHigh), added to the carbon tax, would strongly diminish incentives for conventional generation and lower system emissions, as seen in Figure 42.

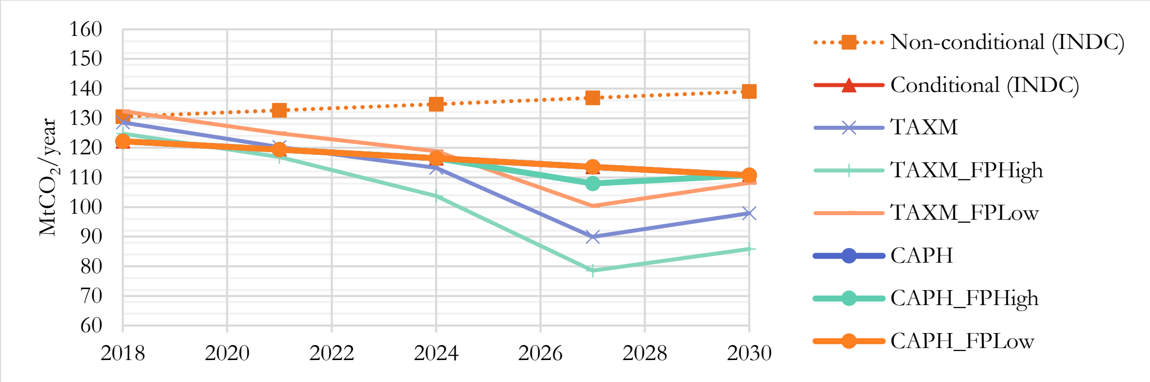


Figure 42. GHG emissions (2018-2030) for TAXM and CAPH scenarios with +/-10% projected fossil fuel prices.

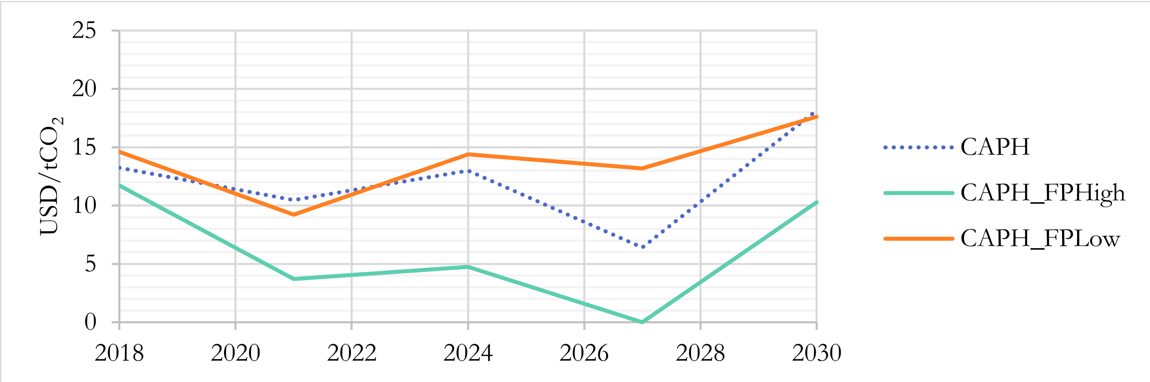


Figure 43. Emission permit price for the CAPH scenario with +/- 10% projected fossil fuel prices.

In the situation of 10% higher and low fossil fuel prices, emissions would still be constrained by the high ambition conditional cap, except around 2027 when the increase in fossil fuel prices would cause a strong increase in renewable capacity, with the resulting depression in the emission permit price observed in Figure 43. It is worth commenting that in the CAPH with low fossil fuel prices scenario the emission permit price behavior is similar, but smoother, than the base CAPH scenario. The permit price oscillates around the 15 USD/tCO_2, very close to the TAXM.

An interesting behavior occurs in the fuel consumption when increasing all fossil fuel prices by 10%. Since natural gas is more expensive than coal, its use is particularly sensitive to the fossil fuel price. Thus, it results in less natural gas usage and reduced demand for emission permits, which in turn allows for more coal consumption. As shown in Figure 44, it is in the high fossil fuel price scenario that coal is consumed the most. A similar situation is observed when varying by +/-10% the projected fossil fuel prices of the TAXM scenario.

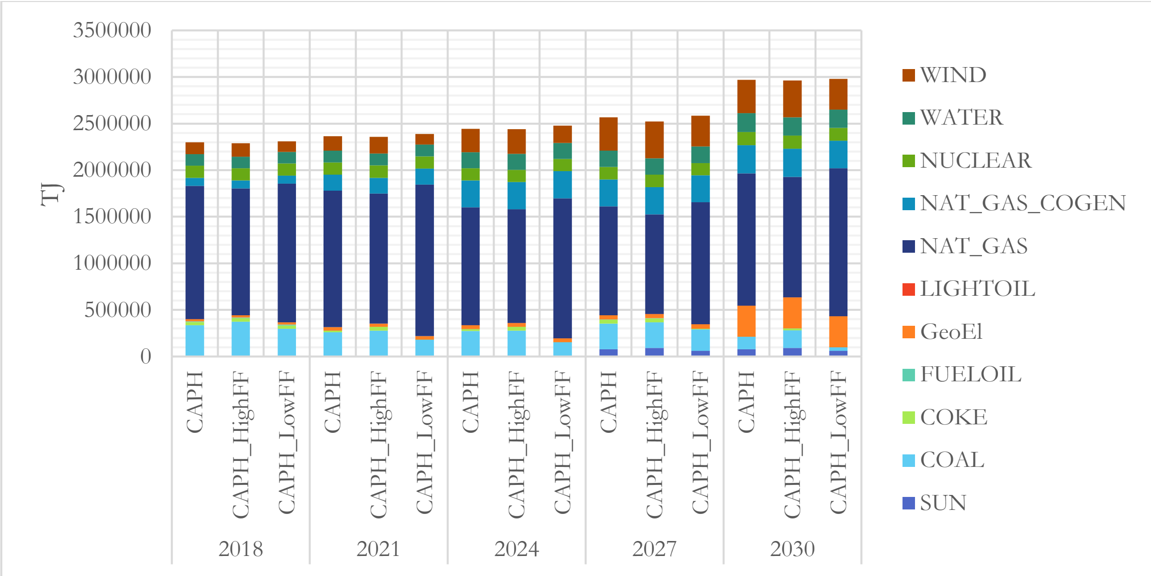


Figure 44. Fuel consumption (2018-2030) for the CAPH scenario with +/- 10% fossil fuel prices.

Adjusting the discount rate

It has been argued that the existing discount rate (set at 10%, see Section 3.1.2) required by the Ministry of finance and public credit (SHCP) is too high to incentivize investment in renewable capacity (which have higher capital costs than combined cycle power plants but no variable costs) (Centro Mario Molina, 2014). As seen in Figure 45 and Figure 46, solar PV and wind generation would be strongly favored if the discount rate was 5%, both in terms of installed capacity and generation. The CAPH and TAXM scenarios reacted similarly to the adjustment in the discount rate.

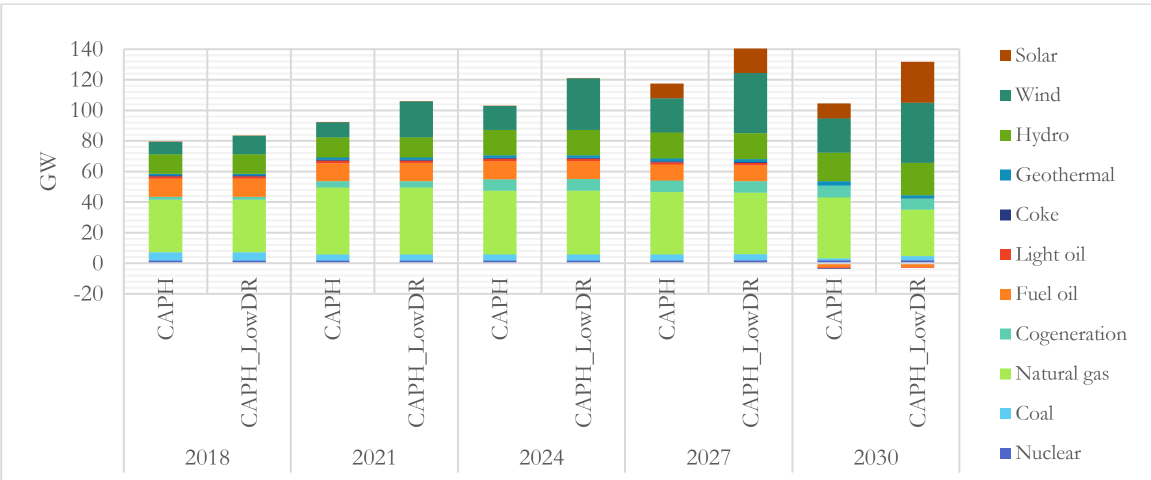


Figure 45. Installed capacity by technology (2018-2030) for the CAPH scenario with the existing and a low discount rate (5%).

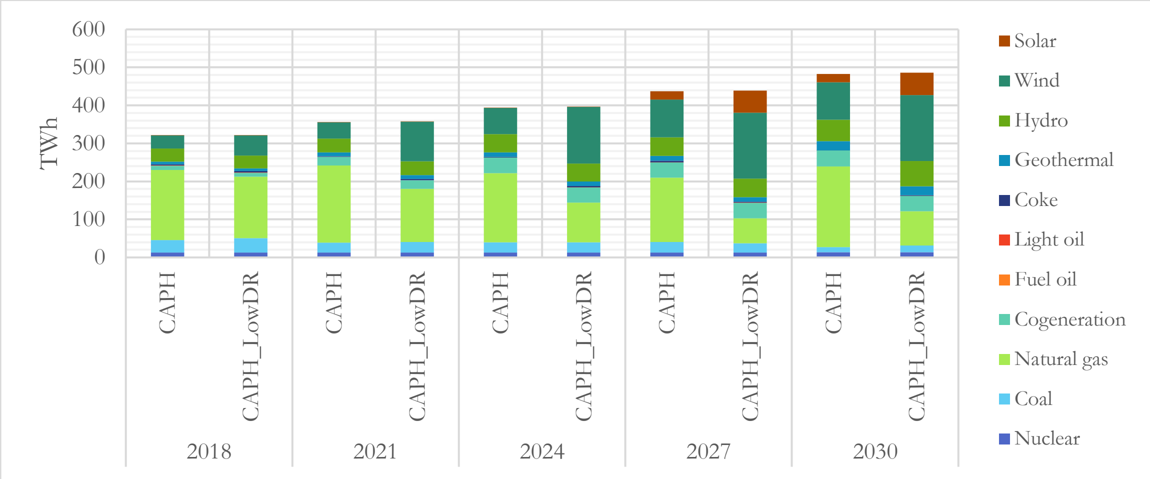


Figure 46. Electricity generation by technology (2018-2030) for the CAPH scenario with the existing and a low discount rate (5%).

The strong increase in renewable energy investment would bring the electricity sector's GHG emissions well below those allowed by the high ambition cap; in this situation, an ETS with a cap set as the conditional target would be non-constraining, with the emission permit at zero throughout the whole period.

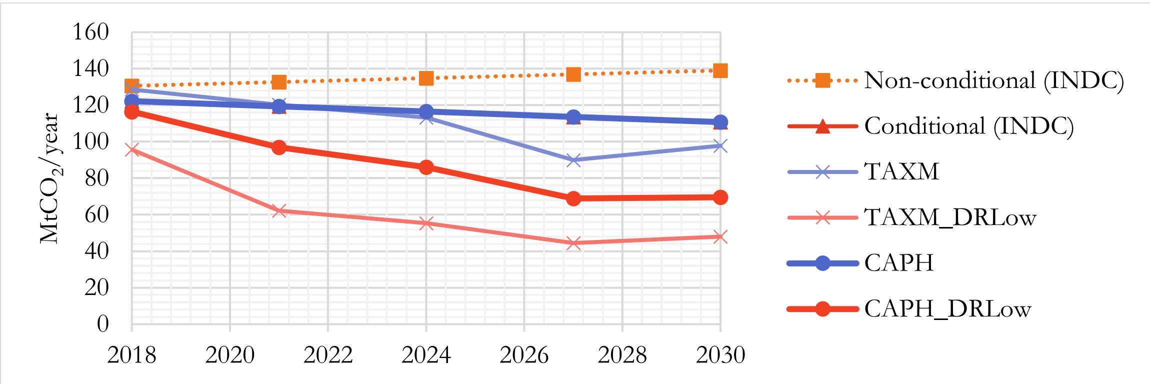


Figure 47. GHG emissions (2018-2030), for the CAPH and TAXM scenarios with the existing and a low discount rate (5%).

A lower required discount rate incentivizes investments with higher capital costs to be done in the short term, as long as they decrease variable costs. As shown in Figure 48, annualized total system for the CAPH scenario would be on average 3% higher in a scenario with 5% discount rate than the originally assumed 10%. For a TAXM scenario, the annualized system costs would be 6% higher. However, electricity prices (see Figure 49) would be on average 15-20% lower than in the 10% discount rate situation.

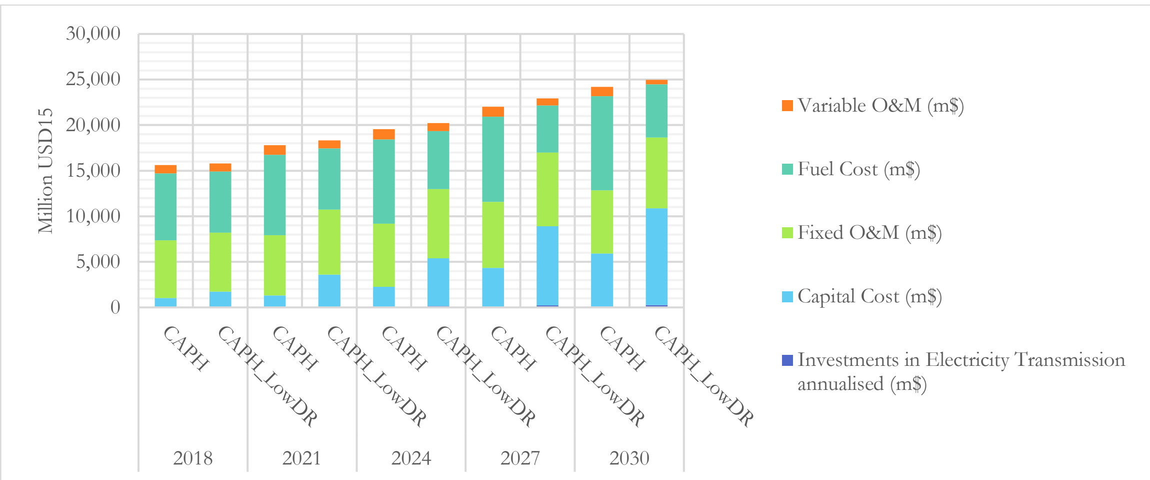


Figure 48. Annualized total system costs (2018-2030), for the CAPH scenario with the existing and a low discount rate (5%).

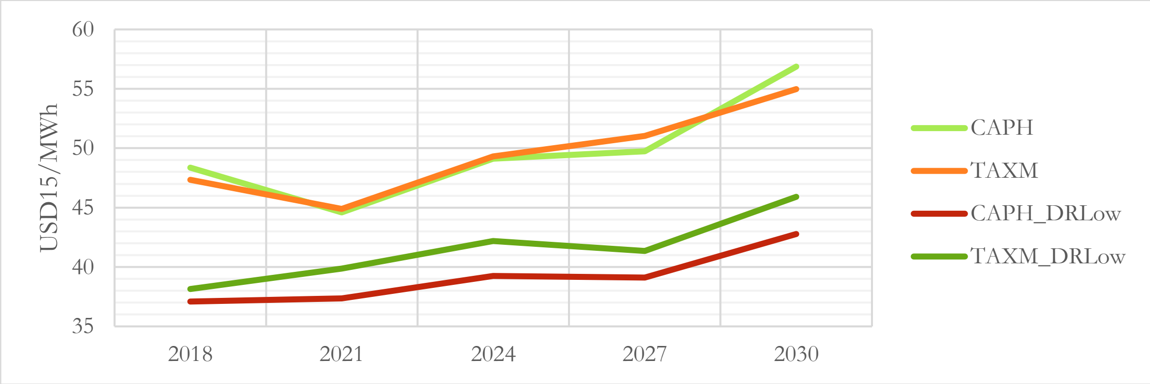


Figure 49. Average electricity prices (2018-2030), for the CAPH and TAXM scenarios with the existing and a low discount rate (5%).

Low availability of natural gas

Due to the risk associated with the dependency on natural gas from the U.S., as well as the insufficient natural gas distribution infrastructure, the possibility of low natural gas availability has been evaluated, by modelling a 10% decrease in national natural gas availability. As is shown in Figure 50 and Figure 51Figure 52, this situation has no effect on the natural gas installed capacity; it remains the same, with new solar PV and wind power installations to satisfy the required generation.

In terms of electricity generation, however, the situation changes. With the CAPH in place, a low natural gas availability scenario in 2030 would see natural gas generation decrease by 24%, with coal increasing by 40%, wind by 28% and solar by 71%. GHG emissions would be below the high ambition cap by more than 10%. With a TAXM in place, the impacts of low availability of natural gas are lower, because the carbon tax already discourages natural gas generation so that it is almost below the availability limits.

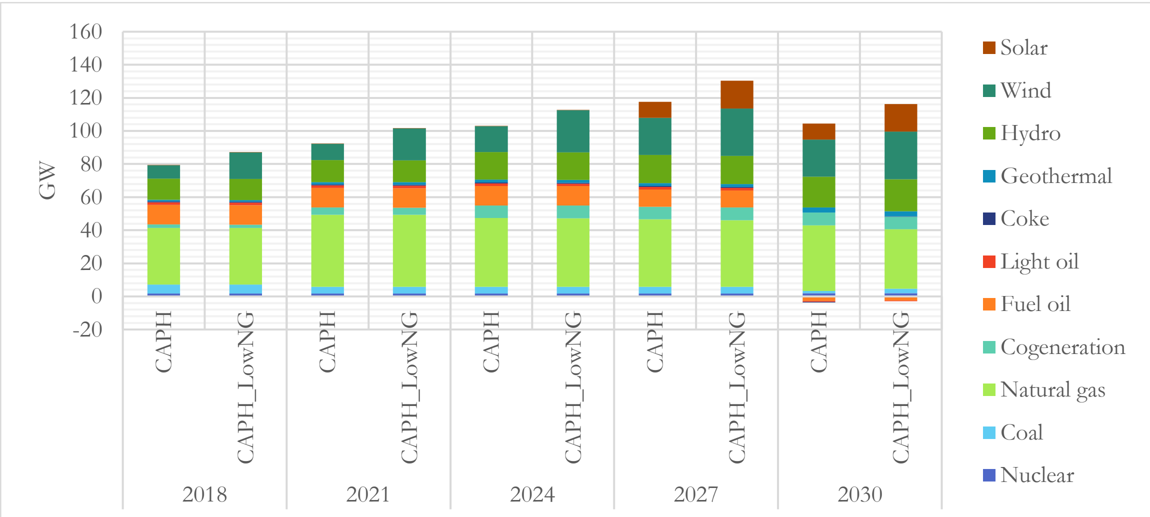


Figure 50. Installed capacity by technology (2018-2030) for the CAPH scenario with a 'normal' and a low availability of natural gas.

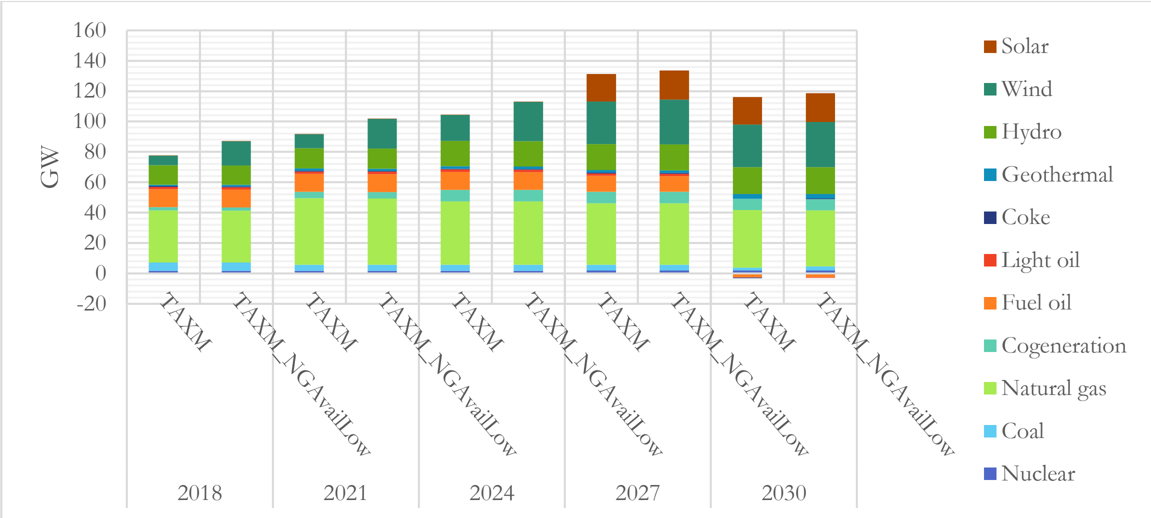


Figure 51. Installed capacity by technology (2018-2030) for the TAXM scenario with a 'normal' and a low availability of natural gas.

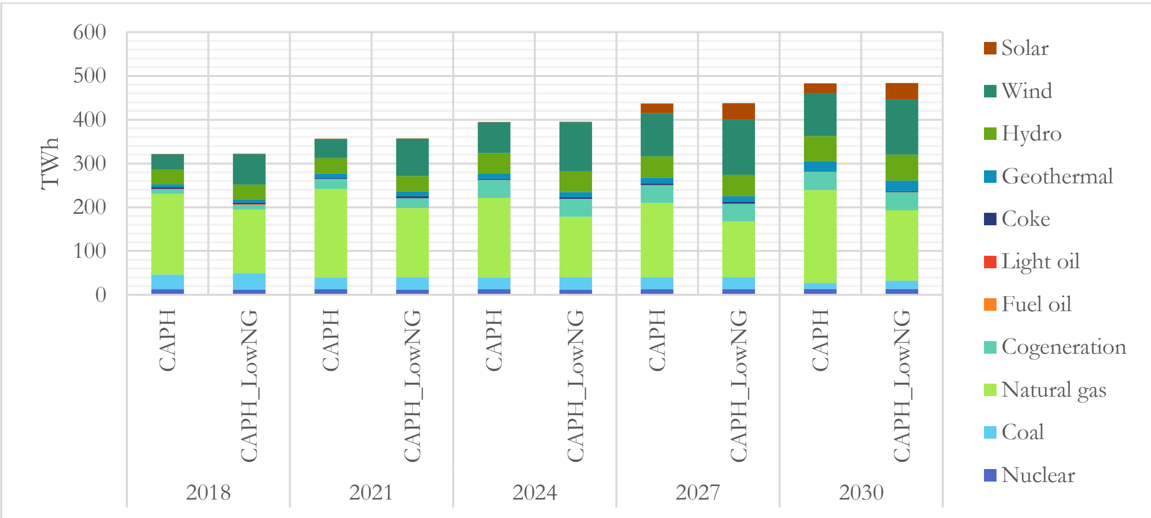


Figure 52. Electricity generation by technology (2018-2030) for the CAPH scenario with a 'normal' and a low availability of natural gas.

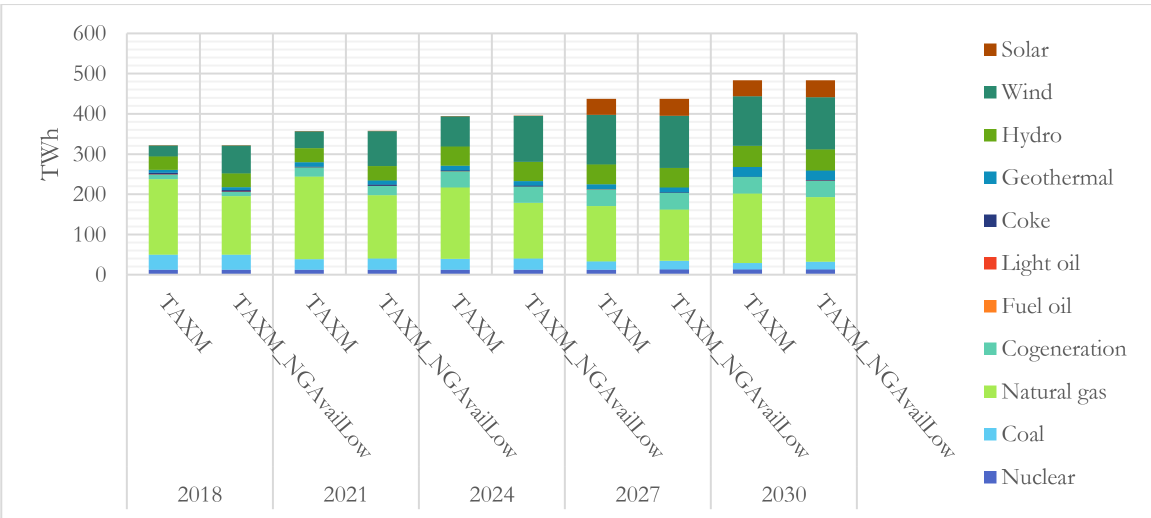


Figure 53. Electricity generation by technology (2018-2030) for the TAXM scenario with a 'normal' and a low availability of natural gas.

Overall, low natural gas availability would have a positive impact on climate change mitigation efforts by increasing emissions reduction from the electricity sector, as seen in Figure 54. The natural gas generation is mostly replaced with wind power generation. However, the electricity price would be on average 6% higher than the CAPH or TAXM scenarios with 'normal' natural gas availability.

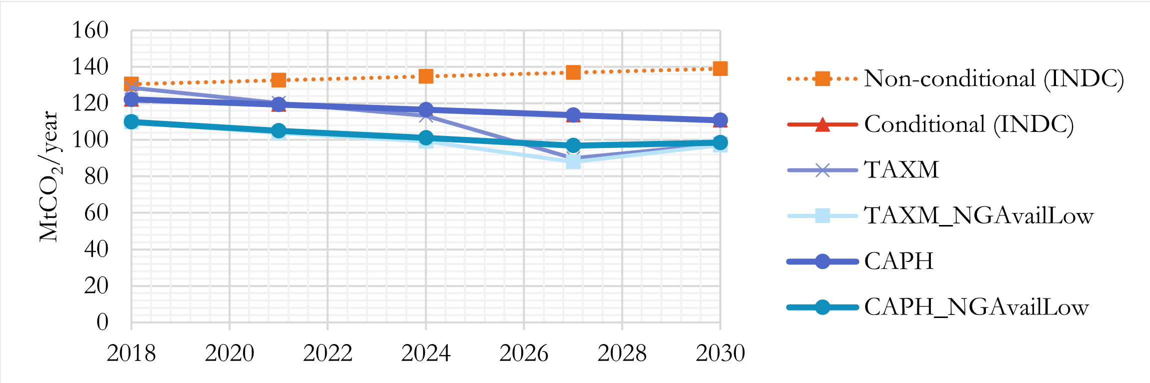


Figure 54. GHG emissions (2018-2030), for the CAPH and TAXM scenarios with a 'normal' and a low natural gas availability.

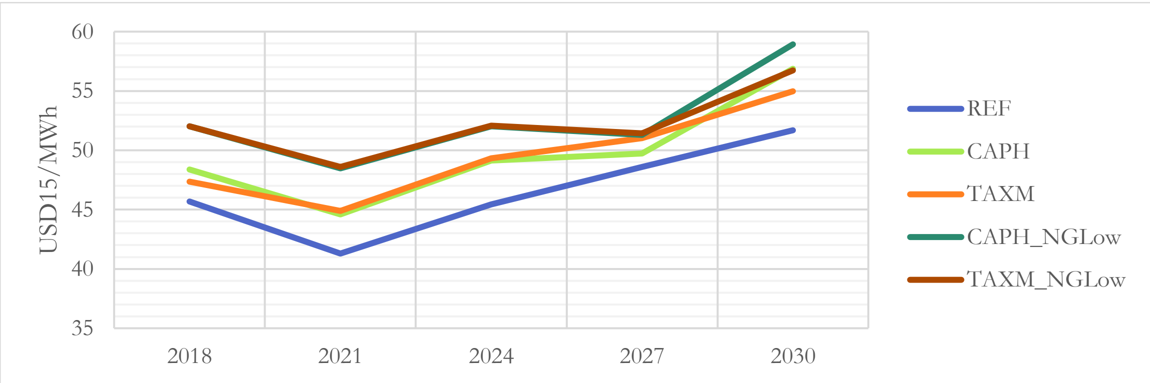


Figure 55. Average electricity prices (2018-2030), for the CAPH and TAXM scenarios with a 'normal' and a low natural gas availability.

5.1.4 Comparing the performance of a carbon tax and ETS based on model-based scenarios of the Mexican electricity sector

After having described the most important results of different tax and ETS scenarios, their economic performance is summarized in Table 10, in terms of the criteria defined in Section 2.2.1. Environmental effectiveness is represented by the GHG emissions and the share of clean electricity generation. Total system costs can approximate the industrial competitiveness criteria, while the installation of clean generation capacity and the stability of the carbon-price relates to the dynamic efficiency. The impact on electricity prices is associated with the distributional effects of an instrument, although the latter are more complex than can be captured with a partial equilibrium model of the electricity system.

Since even the REF scenario was already below the non-conditional emission reduction target, the CAPL scenario is considered not ambitious enough, and was not analyzed further. Similarly, the TAXH scenario is too ambitious (emissions reduction is much lower than required even by the conditional target), and incurs in higher total system costs. Most of the discussion will thus be centered around TAXM and CAPH, as they represent similar ambition levels achieved through different mechanisms.

The required discount rate is a critical parameter regarding the pattern of investment. Renewable generation technologies such as solar PV and wind are strongly favored, as opposed to conventional generation technologies. The interpretation for this should not be that the discount rate should be set at 5%, since it is a parameter with significant macroeconomic impacts whose value cannot be determined lightly; rather, it confirms the claim from previous research that reducing the rate or allowing for more flexibility with regards to energy projects would support the decarbonization of the electricity sector.

Table 10. Comparison of the performance of a carbon tax and an ETS based on model-based scenarios of the Mexican electricity sector.

	Carbon tax	Emissions trading system
Environmental effectiveness (emissions, share of electricity generation)	Emissions depend on the tax rate. The TAXE level creates a slight improvement compared to the REF scenario, but not enough to be below the Conditional target. Both TAXM and TAXH stay below the Conditional target (except for year 2020). TAXH is well below the target (55% of the target in 2030). The TAXM level with natural gas exemption has the same emissions as the REF scenario and does not meet the clean electricity generation targets in certain years. The tax is vulnerable to an increase in the electricity demand, with the risk of emissions being above the conditional target. Even if fossil-fuel prices were 10% lower than projected, the TAXM rate is sufficient to keep emissions below the conditional target after 2024.	The non-conditional target should not be used as the cap for the Mexican power sector, as it represents no constraint. CAPH scenario generates more electricity with natural gas, and less with solar and wind, than TAXM scenario. Generation is always within the targets of clean energy generation. Emission remain unchanged despite having higher or lower electricity demand and fossil fuel prices.
Impacts on competitiveness (Total system costs)	Total annualized costs of all CAP scenarios are almost identical to the REF scenario (except TAXH). The TAXM scenario invests more in new capacity in 2027, and so has higher capital costs, but compensates with lower fuels costs.	Total annualized costs of all CAP scenarios are almost identical to the REF scenario. Higher electricity demand maintains emissions for the CAPH scenario, but increases the average emission permit price by 26%.
Dynamic efficiency (investment in capacity)	TAXM installs more renewable capacity than the CAPH scenario, which has a more unstable price signal. If the electricity demand was 10% higher than expected, TAXM scenario emits 9% more, but maintains a price signal which installs more renewable capacity.	The price depression in the CAPH scenario causes renewable capacity installation to increase less than in the TAXM scenario, and despite the price increase in 2030, it doesn't recover enough to match TAXM installed capacity.
Distributional effects (electricity prices)	TAXM and CAPH scenarios have similar electricity pricing behaviors. Both increase the price of electricity.	TAXM and CAPH scenarios have similar electricity pricing behaviors. Both increase the price of electricity.

5.2 Analysis of international experiences

After the preliminary economic assessment of the carbon tax and ETS for the Mexican power sector has been performed through model-based scenario simulation, this section will provide a more nuanced evaluation of the economic impacts through a review of practical applications of these instruments and the empirical ex-post evidence of their performance. Although the impact of these policies is widespread throughout all economic sectors, the focus of the present analysis has been, when possible, on the electricity sector.

5.2.1 CARBON TAX

The Nordic experience

The Nordic countries were pioneers in the introduction of a carbon tax: Finland and the Netherlands started in 1990, followed by Sweden in 1991, Norway in 1992 and Denmark in 1994 (del Río and Labandeira, 2009). In all of them the tax was introduced as part of a broader environmental tax reform (ETR), the rationale behind this being to reduce taxation from labor or from capital, and shift the burden towards environmental damage such as GHG emissions (Bosquet, 2000). This shift allows the reform to be revenue-neutral (Bosquet, 2000). It is also in this context that carbon taxes are said to have a *double dividend*: there is benefit in living in a clean environment, as there is in higher investment and employment achieved when reducing the tax burden on labor or capital (Bosquet, 2000).

The Nordic tax levels are among the highest in the world (World Bank Group and ECOFYS, 2016). An important feature of the Nordic carbon tax system is that important exemptions exist for energy-intensive industries and for some specific fuels (Lin and Li, 2011). In particular, the electricity sector is mostly exempt from carbon tax, with Sweden exempting electricity producers from the carbon tax, Finland reducing the carbon tax by 50% to combined heat-and-power (CHP) producers, and Norway exempting from the carbon tax the natural gas used in industries encompassed by the EU ETS (European Environment Agency, 2014).

However, the taxation structure has been changing in recent years: for example, although the Swedish energy and carbon tax had been consistently lower for industry than for households, the former has been increasing since 2010 (Swedish Energy Agency, 2016) and is projected to match the general tax rate in 2018 (Raab, 2017). In Finland, the tax rate has also increased in recent years, increasing two-fold in the period 2007-2013 (Bragadóttir et al., 2014). Although the ex-post assessments presented in this section mostly pre-date these taxation changes, they will surely impact the performance of the instrument.

Andersen (2004) reviewed the ex-post literature analyzing the impacts of the carbon tax during roughly the first decade of operation in the Nordic countries; overall, it was concluded that emissions had been reduced relative to a business-as-usual scenario, but not in absolute terms (Andersen, 2004). Bruvoll and Larsen (2004) found only a modest emissions reduction (vs. a business-as-usual scenario) in Norway in the period 1990-99, and attributed this to inelastic demand in the sectors where the tax is levied, as well as important tax-exemptions for industry (Bruvoll and Larsen, 2004).

A more recent study by authors Lin and Li (2011) compares the emissions reduction of the Nordic countries with those of a control group made up of European countries with no carbon tax or similar carbon pricing mechanism (Lin and Li, 2011). They conclude that all countries except Norway have some reduction in emissions per capita caused by the carbon tax, although only in the case of Finland is the result statistically significant (Lin and Li, 2011). It has been argued that the effectiveness of these taxes may be compromised as important tax-exemptions exist for energy-intensive industry, and households are taxed at higher rates than for companies (del Río and Labandeira, 2009) (Lin and Li, 2011). Authors Pardo and Silveira (2013) study energy and CO_2 intensity evolution in the Swedish manufacturing sector, and find that energy and CO_2 taxes have had a significant negative effect on them (Pardo Martínez and Silveira, 2013).

Authors Wier et al. (2005) have found the Danish carbon tax to be more regressive than the average Danish tax, with direct CO2 taxes (levied directly on households) being more regressive than the indirect ones (levied on businesses and transferred to households through consumption) (Wier et al., 2005).

UK carbon pricing

In 2003, the UK introduced the Climate Change Levy (CCL), levied on energy use (fuels and electricity) by industry, commercial users and the public sector (Martin et al., 2014) (Sorrell, 2003). Firms from energy intensive sectors could instead participate in voluntary Climate Change Agreements (CCAs) in which they settled a fixed GHG emission reduction in exchange for paying 20% of the CCL (Martin et al., 2014). Authors Martin et al. (2014) compare firms subject to the full CCL and to 20% of the CCL (CCA participants), and find that the higher price signal given by the full CCL led a significantly higher reduction in energy intensity and CO_2 emissions, mainly due to a decrease in electricity use (Martin et al., 2014). Additionally, they find no statistically significant evidence of negative impacts from the CCL on revenue, employment, productivity or plant exit (Martin et al., 2014).

The EU ETS, introduced in 2005, covered the British electricity generators and a share of their manufacturing firms (Sorrell, 2003). As a response to the low allowances price in the EU ETS, the UK introduced a carbon floor price (CPF) for the electricity generators (Ares and Delebarre, 2016). The CPF functions as a tax: generators buy the auctioned allowances at the EU ETS auctioning price, and then pay a carbon support price, in a way that the total levy is equal to the CFP (International Emissions Trading Association et al., 2015a). The revenue collected from the floor price is directed to general government funds (Carl and Fedor, 2016). Since the introduction of the CPF, coal-fired generation has decreased substantially, and several coal power plants closed in 2016 (Ares and Delebarre, 2016). The UK government recognized the carbon price floor had significantly impacted the competitiveness of energy-intensive industry, and introduced compensation measures in the form of annual support packages starting in 2013 (Ares and Delebarre, 2016).

British Columbia carbon tax

Most recently, the British Columbia (Canada) tax reform has attracted attention, because it provides a good opportunity to analyze the effects of a carbon tax in isolation of other policies; a task which is difficult to perform with any European country's tax because of their interaction with the EU ETS. The British Columbia carbon tax was designed to be the "*purest example of the economist's carbon tax prescription in practice*" (Murray and Rivers, 2015).

An important part of the design is the *revenue-neutrality*, with the carbon tax revenues corresponding in theory to equivalent tax cuts to businesses and households[27] (Murray and Rivers, 2015) (Beck et al., 2015). Initially, tax cuts were directed to businesses and households in general, with stronger support for low-income households; however, since 2012 such cuts are used for the promotion of specific industrial sectors, thus distancing itself from the "pure carbon tax" concept (Murray and Rivers, 2015). In the initial phases, it differed form most existing carbon taxes worldwide in that it offered no exemptions to sectors covered by the tax.

An analysis of a variety ex-post assessments claims that the tax has reduced GHG emissions by 5-15% since its implementation up to 2015 (Murray and Rivers, 2015). There is even evidence to suggest that the decrease in fuel consumption (and the associated emissions reduction) associated with the carbon tax has been stronger than the decrease would have been to any non-carbon tax related fuel price increase (Murray and Rivers, 2015). Empirical evidence suggests that, overall, the economic impacts of the carbon tax are not statistically significant in any direction: there have been some negative impacts in emissions intensive sectors, which have been balanced with positive effects in other sectors (Murray and Rivers, 2015). Authors Beck et al. (2016) use income and expenditure household data and industry input and output tables to study the distributional implications of the tax, and find that the tax is progressive, both with and without the revenue recycling mechanism (Beck et al., 2015). It has also been shown that public support for the tax has increased in the years since the implementation (Murray and Rivers, 2015).

5.2.2 EMISSIONS TRADING SYSTEMS

European Union ETS

The "first trans-boundary cap and trade and the largest air ETS in the world" (Borghesi et al., 2016), the European Union Emission Trading Scheme (EU ETS) started in 2005 with a pilot phase, after a failed attempt at establishing a European-level carbon tax (Convery, 2015).

During the pilot phase (Phase I, 2005-2007), the allowance price was highly volatile and dropped to almost zero by the end of the period (Borghesi et al., 2016). This situation has been attributed to a lack of reliable emissions data at the moment of cap setting, as well as the limitations on allowance banking (allowances

[27] In practice, tax cuts and credits have exceeded the revenue raised with the tax (Murray and Rivers, 2015).

could not be transferred to Phase II) (Borghesi et al., 2016). Free allowance allocation for certain sectors was strongly criticized as it created "windfall profits" (Ellerman et al., 2016). In Phase 2 (2008-2012), the price was slightly more stable, but with a consistent downward trend (Borghesi et al., 2016). Overall, the allowance price decrease has been attributed to a surplus of allowances caused by the economic recession, and to a minor degree by the interaction of the ETS with renewable support and energy efficiency policies (Koch et al., 2014). Emissions have indeed stayed below the cap, but the allowance price doesn't act as an incentive for emissions abatement efforts and long-term low-carbon investments (Hepburn et al., 2016).

The default allocation principle for the EU ETS allowances was set as auctioning in 2009[28] (European Parliament and Council of the European Union, 2009). Although it is the default allocation principle, sectors at risk of *carbon leakage* still have a share of their allowances given for free, with full auctioning being "phased-in" for those sectors (Ellerman et al., 2016). Forty percent of the total allowances were auctioned in 2013, with the share set to increase to over 50% by 2020 (European Commission, 2016).

It has been observed that, contrary to the observed behavior in other sectors, there is almost complete cost pass-through in liberalized electricity markets (Fabra and Reguant, 2014). This is attributed to the practically inelastic demand coupled with a high-frequency auction-based trade (as opposed to markets based on bilateral negotiations) (Fabra and Reguant, 2014). Studies performed with ex-post data from Phases I and II of the EU ETS, when allowances were allocated for free to the electricity sector, suggest that electricity-generation firms internalize the costs of allowances independently of how they are allocated (Fabra and Reguant, 2014). Authors Hintermann et al. (2016) conclude that with free allowance allocation to the electricity sector comes the risk of large firms accumulating excess allowances, driving up the allowance price and creating "windfall profits" for themselves (Hintermann et al., 2016). The stock prices of electricity generating firms in the European electricity market have been shown to be correlated with the EUA price during the Phase I of the EU ETS (Martin et al., 2016). The reasons stated above provide an argument to fully auction allowances to the power sector, a situation in place since 2013 (European Parliament and Council of the European Union, 2009).

An amendment was introduced in 2014 to adjust the volume of allowances auctioned in the period 2014-2016, in an effort to decrease the surplus of allowances in the short term called *back-loading* (European Commission, 2014a). To solve the problem of over-availability in the long-term, a proposal was presented in 2014 to introduce a Market stability reserve (MSR), which would begin operation in 2021. The MSR is a quantity-collar, as it allows to automatically adjust the annual auctioned allowances when the volume of available allowances is larger or lower than predetermined upper and lower thresholds (European Commission, 2014b). In a situation of allowance surplus, a predetermined % of the allowances to be auctioned the following year are not auctioned, and instead put into a reserve (European Commission, 2014b). They may be released from the reserve when the allowances in circulation are below the minimum threshold (European Commission, 2014b). The overall cap remains unchanged, as non-auctioned allowances are simply placed in a reserve to be released later. The MSR proposal is part of a bigger reform package, which is currently in the *trilogue* negotiations among the European Council, European Parliament and European Commission (European Parliament, 2017).

Research has shown that a *price* collar would outperform a *quantity* collar (such as the MSR) in terms of price variation and abatement costs (Fell, 2016; Holt and Shobe, 2016). However, the line between a floor price and a tax is perceived by some actors as very thin, and the European Commission requires unanimity for all decisions related to taxation (European Commission, 2017). This may have encouraged the move towards the more politically feasible quantity-based alternative (Hepburn et al., 2016).

Authors Hintermann et al. (2016) provide various examples where high transaction costs deterred small firms (which usually have allowance surplus) from trading their allowances in the market; for example, only slightly more than 50% of German companies which were covered by the EU ETS actually traded their emissions in 2009 and 2010 (Hintermann et al., 2016). This can create a higher allowance price than the efficient optimum.

Authors Martin et al. (2016) perform a review of scientific research which uses ex-post data from the EU ETS operation to investigate the impacts on the regulated firms (Martin et al., 2016). Overall, the scientific literature provides little to no evidence of a negative impact on competitiveness (exports, trade) and

[28] It came into effect in 2013.

employment in the manufacturing sector (Martin et al., 2016). In general, there is no consensus on the impacts of the EU ETS in low-carbon investment (Borghesi et al., 2016), and it has been suggested that it is the present lack of stringency which is causing such behavior (Rogge et al., 2011). The observed increase in clean innovation since 2005 has been more strongly attributed to feed-in tariffs or renewable energy obligations than to the EU ETS (Martin et al., 2016).

California AB-32 cap-and-trade system

The California CAT started in 2013 (Borghesi et al., 2016). Since the implementation of the CAT, the permit price has stayed stable at around 10-14 USD/tCO_2, with the price gradually increasing from 12 to 14 USD since the linking of the California and Québec cap-and-trade programs in 2014 (California Air Resources Board, 2017). This high and stable price is a clear price signal for low-carbon investments, but no ex-post assessment of the impact low-carbon investments is publicly available.

It is argued that one of the reasons for the stable price is the fact that GHG emissions have been reported since 2008, which gave policy-makers reliable emissions data when setting the cap (International Emissions Trading Association et al., 2015b). Another critical design feature is the annually-rising floor price for the auctioned permits (Bailey et al., 2012), which has led the California CAT to have the highest emissions permit price worldwide among mandatory ETS (Borenstein et al., 2015). Additionally, the California cap-and-trade program has introduced a price containment reserve to avoid too high prices: 4% of the annual budget of emission permits is directed to the reserve which may be released when the permit price reaches a predetermined threshold (International Emissions Trading Association et al., 2015b). If the reserve is exhausted, 10% of the permits from future years may be transferred to the reserve (International Emissions Trading Association et al., 2015b).

As a protection against manipulation and market power, the California cap-and-trade program has introduced *holding limits*: a constraint on the number of permits that a single firm may hold, which hampers the firm's possibility to manipulate prices for their advantage (Borenstein et al., 2013). Holding limits are absolute, meaning that they are the same for every firm regarding the firm's volume of emissions (International Emissions Trading Association et al., 2015b). Arguments to transform them into limits relative to the compliance obligation of each firm have already been raised (Borenstein et al., 2013).

A lawsuit is in place since 2012 by the California Chamber of Commerce against the California Air Resources Board (Environmental Defense Fund and Natural Resources Defense Council, 2017). Proponents of the lawsuit argue that the California floor auction price effectively constitutes a "tax", which would have required a two-thirds majority to be approved by Legislature, whereas it was only approved by a simple majority (Environmental Defense Fund and Natural Resources Defense Council, 2017). The lawsuit has not been resolved, but there are reasons to believe the auctions will be supported by the judges (Energy Innovation, 2017). The allocation of the revenue collected is considered an important metric for deciding whether it should be considered a tax or a fee. The situation reminds of the negative of the European Commission to introduce a carbon floor price within the EU ETS for similar reasons.

Chinese pilot ETS

When fully operational, the Chinese ETS will be the world's largest emissions trading system (International Carbon Action Partnership, 2017). Although still in the initial stages, ex-post assessments have been performed analyzing the behavior of some or all of the seven regional emission trading pilot schemes during their first years of operation (Cong and Lo, 2017; Munnings et al., 2016; Xiong et al., 2017; Zhao et al., 2016). The challenges encountered during these years yield important learnings for other emerging ETS.

Emissions data quality has been a major challenge in the operation of the pilot ETS, due to insufficient penalties for data falsification or obstruction, as well as a lack of experience emissions data reporting (Munnings et al., 2016). This has negative consequences in the setting of an appropriate cap. Enforcement has also proved difficult under the pilot ETS, mainly due to the lack of a National-level legal framework which would allow the imposition of a sufficient penalty on non-compliant firms (Munnings et al., 2016).

An interesting feature of the Chinese pilot ETS is the use of intensity-based caps, set in terms of tCO_2 per unit of GDP. Although absolute caps are the most common type of cap amongst jurisdictions with an existing ETS (World Bank Group et al., 2016), a relative cap is advantageous for a developing country such as China, where the economic growth is difficult to predict (Jotzo and Löschel, 2014). In practice, the intensity-based cap has led to an annual cap setting with further within-period adjustments, which has created uncertainty for regulated firms and kept market liquidity very low; trading happens mostly in the last stages of the compliance period, when the permit allocation is known and fixed (Munnings et al., 2016) (Zhao et al., 2016). But, sufficient liquidity is necessary to ensure that the permit price accurately reflects marginal abatement costs (Munnings et al., 2016), as well as to avoid strong price fluctuations (Zhao et al., 2016).

In some of the pilots, the 10 largest firms hold 60-70% of all permits (Zhao et al., 2016), with the ensuing risk of price manipulation. The Shanghai pilot, similar to the California cap-and-trade system, has introduced holding limits; however, due to lack of good-quality emissions data it is unclear whether the limits are binding (Munnings et al., 2016).

LESSONS LEARNT FROM INTERNATIONAL EXPERIENCES FOR AN ETS DESIGN

As opposed to a carbon tax, which allows to set a *stable* carbon price in a relatively straightforward way[29], in an ETS there is a myriad of factors which can cause carbon price volatility. As it has been recognized that a strong and stable carbon price is critical in driving low-carbon investment, effort is directed towards designing the ETS in a way that the emission permit price is relatively stable, not subject to market manipulation, and that it reflects the marginal abatement costs. The market design features are critical to achieve these objectives. The lessons learned from the previously described experiences are summarized in Table 11.

Table 11. Learnings for ETS design based on international experiences.

Cap setting	Good quality emissions data prior to the operation of the scheme is imperative. Although relative intensity-based based caps can help reach relative emissions intensity targets, they have been shown to restrain market liquidity.
Allowance allocation	Free allowance allocation for the electricity sector is not justified; permits should be auctioned. Initial free allocation of allowances has been required in the past to gain the buy-in of participating firms.
Price signal	Allowance banking plays a critical role in stabilizing the allowance price above a minimum. A carbon floor price for the auctioned permits ensures a stable price signal. Caution should be exercised as opponents may associate floor prices with a carbon tax. The effectiveness of a quantity-collar (market stability reserve) for stabilizing the price signal remains to be proved.
Risk of market manipulation	Holding limits decrease the risk from market manipulation by dominating actors.
Transaction costs	High transaction costs relative to size of the smallest firms can deter them from trading, decreasing the overall efficiency.

5.2.3 COMPARING THE PERFORMANCE OF A CARBON TAX AND ETS BASED ON INTERNATIONAL EXPERIENCES

After having described the most important features of the carbon-pricing instruments of different jurisdictions, their performance is assessed in terms of the following criteria: environmental effectiveness, impact on industry competitiveness, dynamic efficiency, and distributional effects, and summarized in Table 12.

[29] Whether the level of the tax is correct is another matter.

Table 12. Comparison of the performance of a carbon tax and an ETS based on international experiences.

	Carbon tax	Emissions trading system
Environmental effectiveness	A tax with wide-coverage and no exemptions is effective for reducing emissions.	Emissions always stay below the cap.
Impact on industry competitiveness	A revenue-neutral tax (tax cuts and credits for business and households) has no negative impact on overall industry competitiveness. Governments protect energy-intensive industry by exempting them from the tax or introducing compensation measures.	There is little evidence of a negative impact on competitiveness of existing ETS. However, the impact on competitiveness following the increase in the share of auctioned allowances should be monitored.
Dynamic efficiency	The price signal of a carbon tax is stable by design. However, tax exemptions may distort this signal.	A low and unstable allowance price doesn't incentivize low-carbon investment. A floor auctioning price helps maintain the price signal high and stable. Alternatives to a floor price exist, but there is no evidence of their performance yet.
Distributional effects	A flat carbon tax is generally regressive. This can be compensated by a well-designed revenue-recycling mechanism.	Free allowance allocation to electricity producers leads to "windfall profits" and is regressive. Analyzed emissions trading instruments didn't include any revenue-recycling provisions.

Both instruments are effective for reducing emissions in the electricity sector. The impact on industry competitiveness can be modulated for both: revenue-recycling is an effective way of compensating for impacts on competitiveness caused by the tax, while the free allocation method in an ETS allows to protect particularly sensitive industries. However, the electricity sector is not an industry at risk in either situation.

The two criteria which greatly differentiate these two instruments in the context of the electricity sector are dynamic efficiency and distributional effects. The stable price signal created by the tax creates incentives to low-carbon investment within the electricity sector, whereas only an ETS with a floor auctioning price would be effective in this regard. Regarding distributional effects, taxes are traditionally best suited for revenue-recycling mechanisms to compensate for the innate regressive nature of carbon-pricing, while no examples exist of revenue-recycling in the context of an ETS.

5.3 Survey and interview results

Previous sections presented evaluations on the economic effects of the two carbon-pricing instruments. This section now aims to explore whether it is feasible to establish either of these instruments for emission reduction in the Mexican electricity sector, and which design characteristics they should have to facilitate their introduction. This assessment is performed based on the results of the on-line survey and the interviews.

5.3.1 ANALYSIS OF INTEREST GROUPS' PREFERENCES

Before moving on to the preferences of the interest groups, it is important to note that 87% of the respondents were aware of the existence of a tax levied on the carbon contents of fuels, whereas only 74% were aware of the emissions trading exercise in progress. The ETS exercise started only in 2017, and only close to 100 industrial companies are represented; on the other hand, the carbon tax has a high visibility, as it is levied among other things on transportation fuels. The following section will briefly describe the results, while a more detailed account in graphic form can be found in the Appendix 7.2.

GENERAL PREFERENCES

Almost half of the respondents prefer an ETS as the cornerstone of Mexican climate change mitigation policy, with 36% of respondents preferring a carbon tax, and 15% preferring command and control instruments. Electricity generators, service companies and representatives of the public sector were the most favorable to ETS, while NGOs gave preference to a carbon tax, and Industry and Academia were divided among the three possibilities. It is particularly interesting to note that more than a third of Industry respondents preferred command and control instruments, despite it being commonly argued that carbon pricing instruments represent the most cost-effective way of reducing emissions.

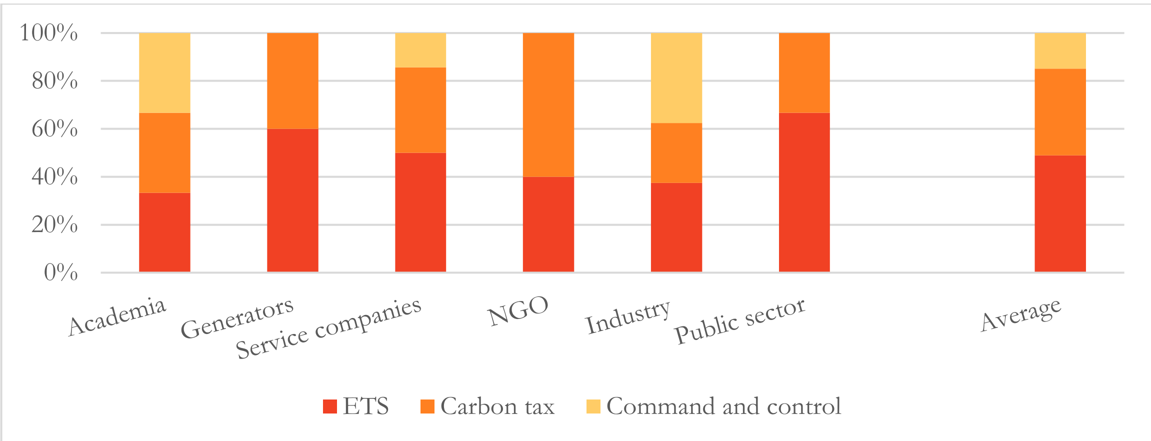


Figure 56. Survey results: instrument preferences per interest group.

There is agreement among all groups about the importance of low-carbon investment as a criterion for instrument evaluation. Some interest groups have clear priorities: for industry and electricity generators, stimulating low-carbon investment is the definite winner, while academia prioritizes cost-effectiveness, and NGOs give equal important weight to stimulating low-carbon investment, behavioral change and distributive equity. Other actors have larger internal variation: it is harder to pinpoint a single priority for service companies and the public sector, although cost-effectiveness and stimulating low-carbon do get higher gradings. Such behavior fits the role which the public sector could take as a mediator or synthesizer between different interest groups. The full account of the interest groups' priorities can be found in Appendix 7.2.

As can be seen in Figure 57, there is almost unanimity regarding the use of the carbon revenue: 83% of total respondents agree it should be earmarked towards climate change mitigation programs. This response is interesting as the Mexican Constitution states that all tax revenue must be directed to the general budget, with no opportunity for ear-marking. On the other hand, revenue from permit auctioning in the ETS could be directed to climate change mitigation programs.

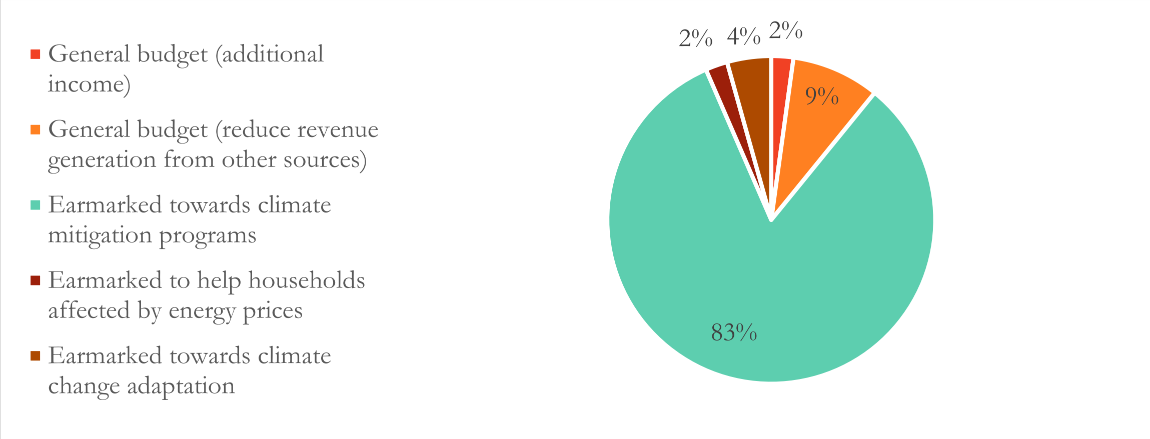


Figure 57. Survey results: preferences for the use of carbon revenue.

CARBON TAX

The current carbon tax, at 40-50 pesos/tCO_2, is lower than the originally proposed 70 pesos/tCO_2. As shown in Figure 58, industry respondents considered this to be the correct tax level, while electricity generators consider it to be in the range of correct to high. Overall, service companies, NGOs and academia consider the tax to be low, while the public sector had the most internal variety of responses, with "correct level" still emerging as the most popular.

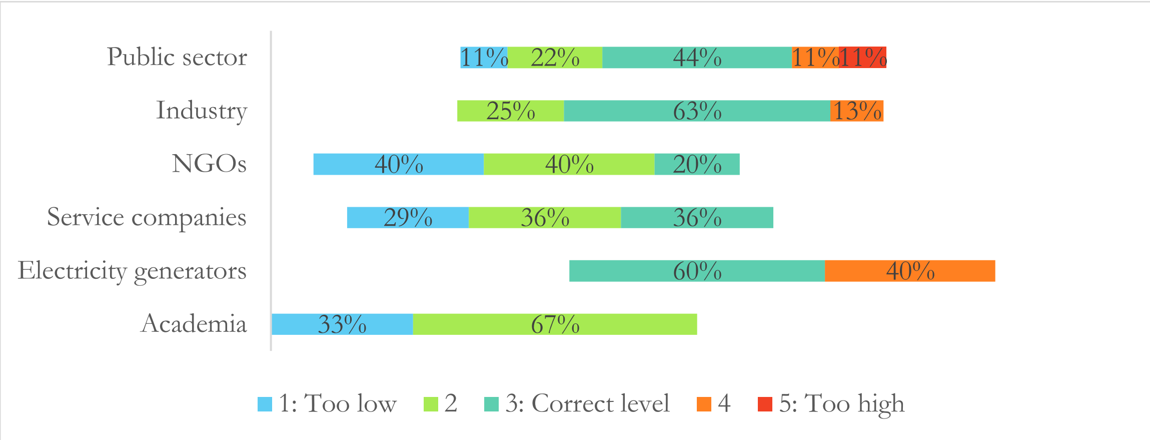


Figure 58. Survey results: evaluation of the existing carbon tax level per interest group.

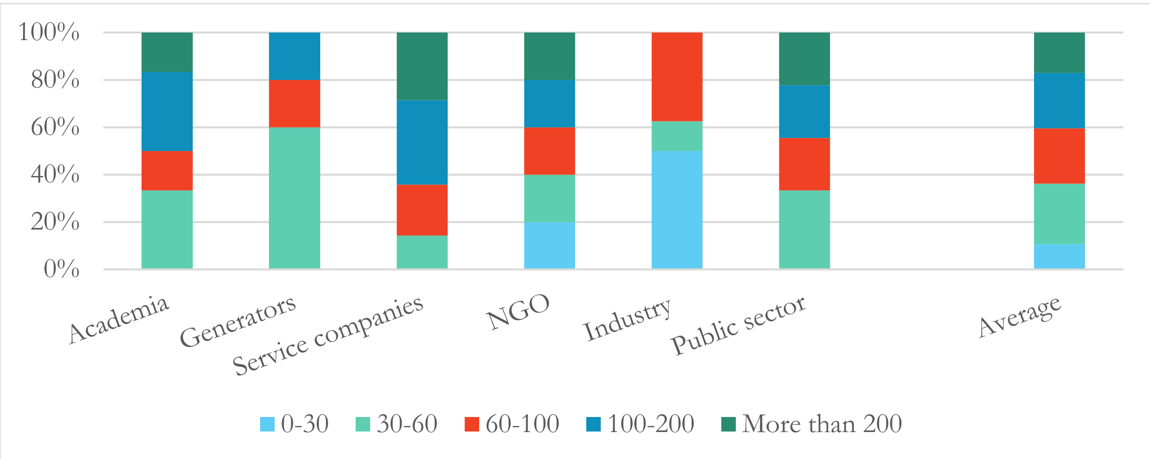


Figure 59. Survey results: preferred tax level range (pesos/tCO2) per interest group.

Additionally, five tax level ranges were provided to the respondents, who were asked to select their preferred level. The lowest range was 0-30 pesos/tCO_2, and the highest more than 200 pesos/tCO_2. As seen in Figure 59, no clear consensus emerged from this question. Ordered from lower to higher desired tax level, industry would be the first (it is the only interest group for which half of respondents prefer a tax level of 0-30 pesos/tCO_2), followed by electricity generators, public sector and NGOs. Interest groups who favor a high tax rate are service companies and academia.

There is agreement amongst interest groups when it relates to the role of natural gas carbon taxation (see Figure 60). Industry clearly state that natural gas should not be taxed at all. Generators and the public sector generally prefer it to be taxed at a lower level per carbon content compared to other fuels. NGOs and service companies all consider it should be taxed, but are divided between whether it should be at the same level of other fuels, or lower. Academia is clear that natural gas carbon contents should be taxed at the same level as that of other fuels. These responses anticipate the discussion that will emerge later about the role of natural gas in the decarbonization of the Mexican electricity sector.

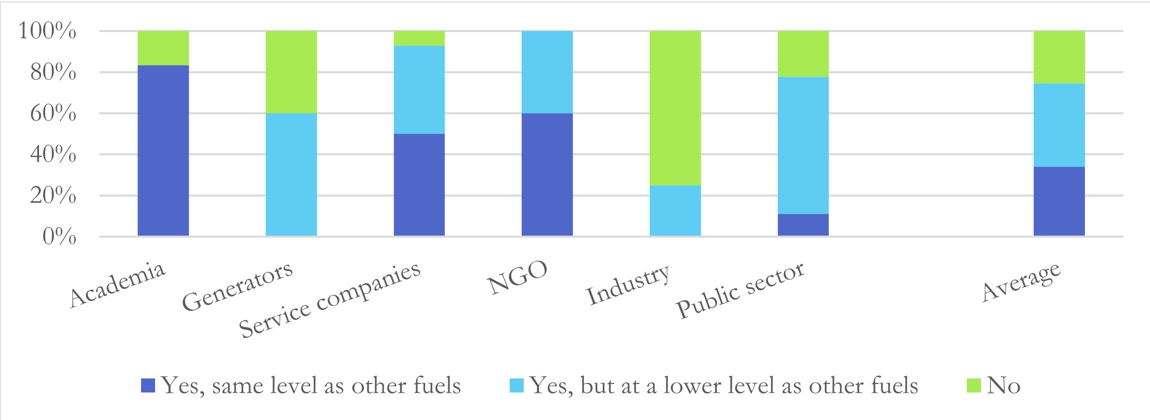


Figure 60. Survey results: responses to "should a tax be levied on natural gas based on its carbon contents?", per interest group.

EMISSION TRADING SYSTEM

Regarding a potential Mexican ETS, the preferred permit allocation mechanism for the electricity sector differed across interest groups. Academia and NGOs favor full auctioning, although 40% of NGO representatives took a softer stance with some permits being auctioned and some for free. Industry and electricity generators favor free allocation of permits, either based on historical emissions or on benchmark, although a few representatives of each group stated preferring a mix of free and auctioned permits. Service companies and the public services have more divided responses, ranging from free permits, auctioned permits, and a mix of both.

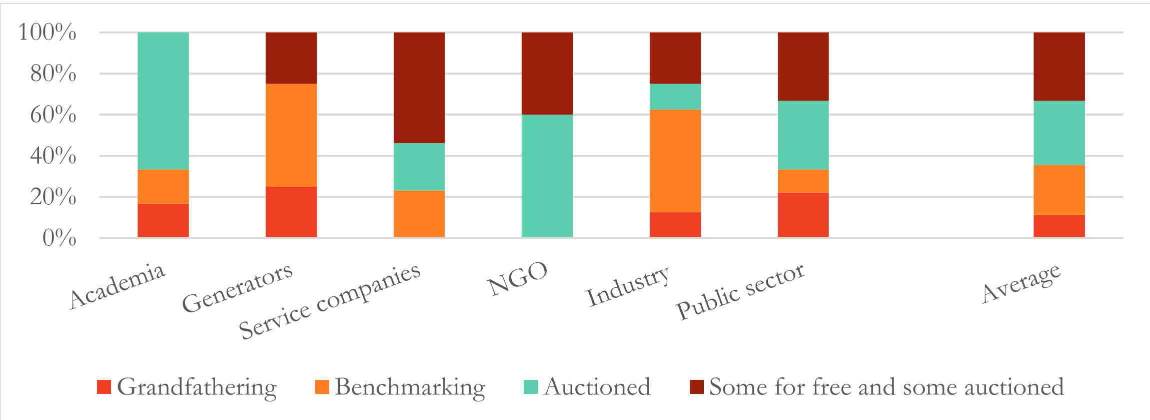


Figure 61. Survey results: preferences regarding allowance allocation to the electricity sector, by interest group.

With the aim of exploring the preferences of actors regarding specific ETS design features, there was a set of questions where each ETS design feature could either "be used" or "not used" (with the possibility of responding "I don't know"). Given the lack of Mexican experience with an ETS, an initial screening of responses was performed: only respondents whose stated "level of knowledge" of ETS was above 3 or more (in a scale of 1-5) were considered. Additionally, respondents who stated that both absolute cap level and relative cap level should be used were removed from the analysis of this question, as these two attributes are considered mutually exclusive. This initial screening removed more than half of the respondents, leaving only 22 responses. The results are shown in Figure 62.

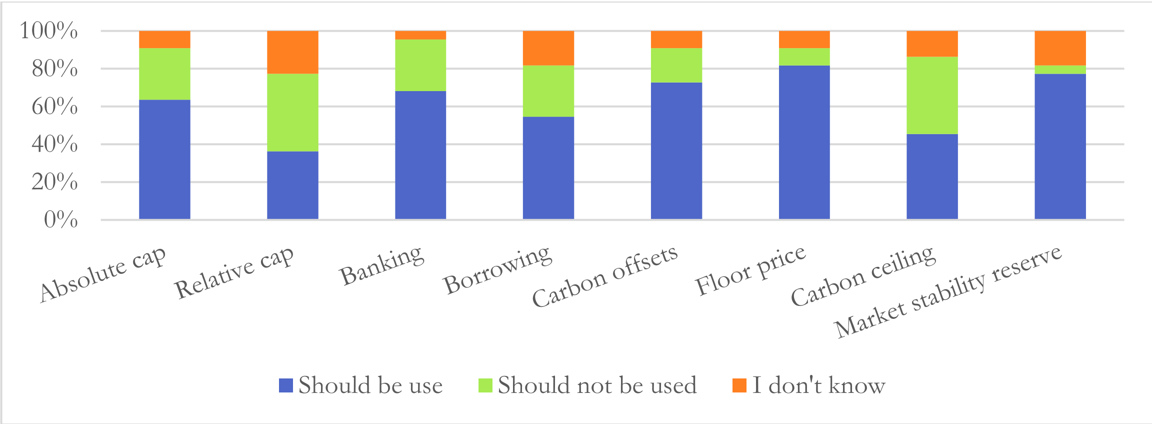


Figure 62. Survey results: preferences regarding ETS design features.

A higher share of the screened respondents prefers an absolute cap to a relative cap. Features such as banking and the use of carbon offsets we approved by close to 70% of screened respondents. More than 80% recommend using a carbon price, with less than 50% recommending a carbon ceiling. More than 70% stated that a market stability reserve should be used. Again, these results should be taken with caution: a market stability reserve and a carbon price could be argued to be mutually exclusive, as one is a quantity collar and the other a price collar. These results could be interpreted to mean that some price control mechanism should definitely be introduced, and that either of them could be an alternative. In retrospect, the wording of the survey questions in this particular section should have been different, opposing for example an absolute vs. relative cap, and a price collar vs. quantity collar.

COMBINING CARBON-PRICING INSTRUMENTS

In theory, a carbon tax and an emissions trading system are equivalent, and the choice merely resides in choosing one or the other. As has already been commented, Mexico already levies a tax on the carbon content of fuels, and is preparing to launch an emissions trading system in the next few years. Assuming this situation is maintained, how should these two instruments be combined? This inquiry was part of the final open questions in the survey, which received 22 responses.

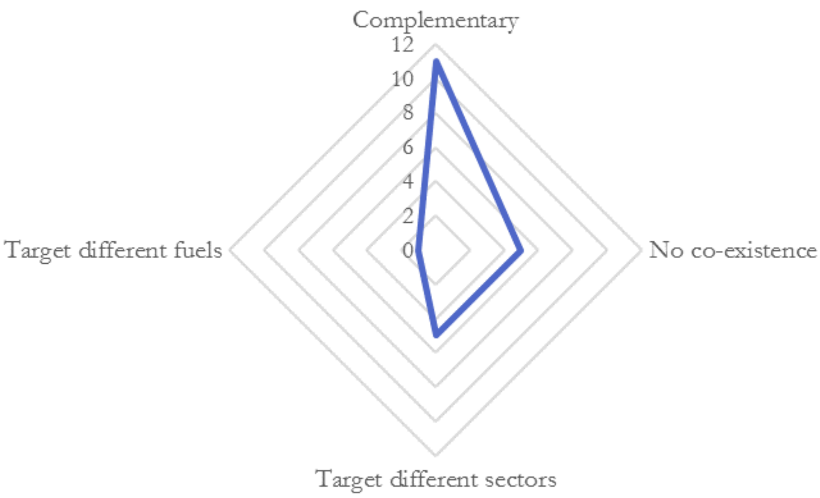


Figure 63. Survey results: preferences regarding carbon-pricing instruments co-existence, per number of survey responses.

Most respondents mentioned that they could be complementary, with responses ranging from the tax setting the floor price of the ETS, to tax obligations being deduced with emission permits or clean investments. In addition, some specified that the two instruments could target different sectors (carbon tax targeting sectors not covered by ETS, such as transport), or even different fuels. Five respondents stated that these should not exist in parallel, some specifying that only the ETS should be maintained, or that implementation should be sequential (probably referring to the now repealed Australian system – a fixed carbon pricing system followed by a system with a flexible price, determined by an ETS). The full list of answers can be seen in Appendix 7.2. Overall, most respondents were comfortable with the idea of both instruments existing simultaneously. This topic raises the question of the coordination between different governmental actors, as these instruments are currently handled by different Ministries. This will be further discussed in the Discussion chapter.

CHALLENGES TO GHG EMISSIONS REDUCTION IN THE MEXICAN ELECTRICITY SECTOR

Survey respondents were also asked about the challenges of decarbonizing the Mexican electricity sector, and 23 answered. The complete list of responses has been included in Appendix 7.2. The important themes identified are shown in Figure 64.

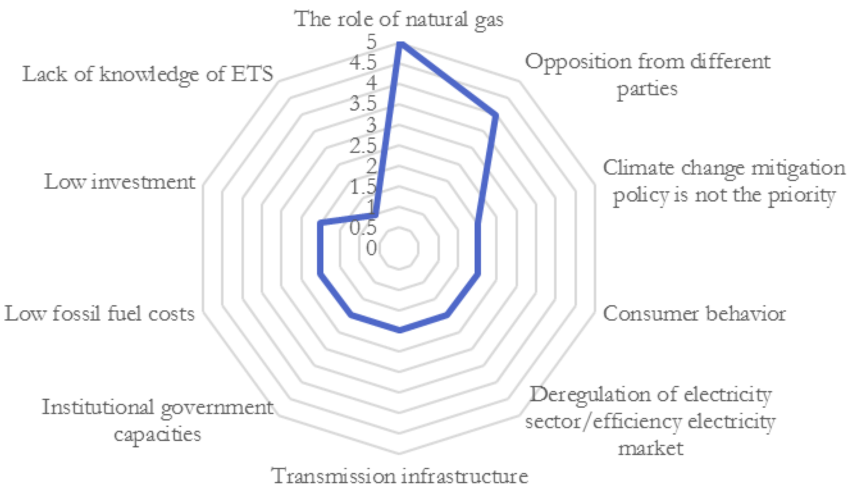


Figure 64. Challenges to reducing GHG emissions from the Mexican power sector, per number of survey responses.

As reflected by the diverse and sometimes opposing views from different interest groups regarding natural gas taxation, is it not surprising that the role of natural gas has been the most recurrent theme regarding the challenges of decarbonizing the Mexican power sector. Although there seems to be agreement that natural gas plays an important role in the electricity sector, two diverging trends can be identified: those who see the bet on natural gas as creating a long-term carbon lock-in for the electricity sector (representatives from NGO, academia and public sector), versus those who state that natural gas should be further promoted as it is clean and reliable (representatives from industry and services companies), and that the risk rather resides in a potential lack of availability of this resource.

As can be further observed in Figure 64, opposition from industry or other affected parties has also been a recurrent theme. This sets a good base for the following conversation regarding the climate change mitigation policy development and the role of the different interest groups in determining the level of ambition and the instruments to be used.

5.3.2 ANALYSIS OF INTEREST GROUPS' RELEVANCE IN THE POLICY-MAKING PROCESS

According to the survey results, *industry* and *legislators* are the most influential actors in the climate policy-making process, reaching consensus amongst representatives of all respondent interest groups. *Public officers* are also considered influential to very influential by most respondent groups, except by a majority of industry respondents who consider their level of influence medium (level 3 in a scale of 1-5). *Large scale electricity generators* came next in terms of relevance, with a share of all respondent groups considering them influential to very influential, but with a larger share considering their influence level medium. *NGOs*, *small-*

scale generators, *academia* and *service companies* could overall be considered to have a medium level of influence. The detailed results can be seen in the Appendix 7.2. These results correspond to the discussions which emerged during the interviews, that *industry* and the *public sector* are consistently mentioned as the most influential.

THE LEVERAGING OF POWER BY INTEREST GROUPS

The level of influence held by each group partly stems from the way these groups organize. Industry presents a common unified front which is more influential than individual companies. Less powerful groups collaborate with the most influential to push their agenda. This sub-section aims to explain how this is done within the context of climate policy-making in Mexico, based on the insights obtained from the interviews.

The Federal government leads the discussions on the implementation of climate policy, always within the framework of the General Law on Climate Change. The Inter-Ministerial Council on Climate Change (CICC) is presided by the Ministry of Natural Resources (SEMARNAT) but includes all other Federal Ministries, such as the Ministry of Energy, Ministry of Public Credit, Ministry of Agriculture, and others. This is a structure which allows for the climate actions of the different Ministries to be coordinated. Within the Ministries of the Federal government – in the present or past administrations – there are individuals who have played a leadership role and stand out as having moved forward the climate agenda.

Academia and NGOs usually collaborate with the public sector. It is through this collaboration that they leverage their influence and try to push for an ambitious agenda. They participate in the Climate Change Council, which has supported the elaboration of specific documents such as the National Climate Change Strategy or the Climate Change Special Program. It should be noted that the line between NGOs and academia may at times be blurred, as reflected for example in the influential Centro Mario Molina, a non-governmental non-for-profit organization composed of prominent researchers such as the Chemistry Nobel Prize Winner Mario Molina. Together, the Federal government, academia and NGOs guide the normative conversation about how to best abate emissions.

There are instances, however, when the interests of these groups are not aligned. For example, the importance given to natural gas as a transition fuel and the fact that it has a tax rate of zero was a decision made by the Federal government ministries. Despite opposition, election campaign commitments regarding the lowering of electricity tariffs and matters of energy security prevailed.

The private sector can be said to be represented by two groups with mostly, but not fully, overlapping interests. The Confederation of Mexican Industrial Chambers (CONCAMIN) groups the regional industrial chambers as well as the sectorial chambers (such as the chamber of steel, cement or chemical industry). There is, on the other hand, the Enterprise Coordination Council (CCE), which represents services companies, banks, electricity generators, among others. Both are aligned in the priority they give to market-based mechanisms, particularly to an ETS, to maintain industrial competitiveness. However, they differ in the design features of the instrument.

The private sector lobbying addresses the Ministries in the first place; they may address legislators in a second stage. They intervene in the informal negotiation phase, before the draft document of legislation/rules is released for public consultation. Their level of influence in matters of climate policy is very high (as opposed, for example, to their low level of influence in fiscal policy). This influence is reflected in the definition of "clean energy" stated in the Law of Energy Transition, which was modified to include fossil-fuel based technologies with carbon capture and storage.

The largest actor within the electricity generators, CFE, is not associated with the private sector as it is still state-owned. The role of private conventional electricity generators in the ETS design will be defined by the threshold set for participating in the system. Renewable electricity generators are organized in groups such as the association for solar energy, SOLMEX, or for wind energy, ANES. Service and consulting companies ally with the private sector to further promote industrial competitiveness; they are interested in developing emissions trading capabilities within the private sector.

THE POLICY-MAKING PROCESS AND THE STATUS OF THE CARBON-PRICING DEBATE

The debate over Mexican climate policy could be described in two steps. Around 2007-2008[30], there was a national debate over the level of ambition regarding climate change mitigation, which was to be established in the first Climate Change Special Program 2009-2012. Different interest groups were involved in this debate, which was led by the Federal government through the CICC. There was a round of public consultations including the private sectors, NGOs and academia. The initial governmental proposition was considered overly ambitious by some actors, and what emerged from the debate was the still ambitious but conditioned (to international support) target of halving GHG emissions by 2050 compared to 2000. This indicative target was then set in the 2012 General Law on Climate Change (LGCC), and used as a basis for the conditional target in the Mexican INDC to the COP21.

The initial debate has somehow been settled. Within the Federal government, there is consensus regarding the existing climate policy and its level of ambition. This transversal agreement is not merely vocal, but is reflected in the public policies of all Ministries. Only a minority –but influential – group, namely the steel industry, continues to question this on the grounds of increasing costs to the industry at a moment when the United States of America is cutting back on their previous engagements.

The second phase of the climate policy debate relates to *how* this goal will be achieved. The mention of market-based instruments in the LGCC can be at least partly attributed to the recent international trend of introducing carbon-pricing mechanisms in the national mitigation strategies. It is in this context that such type of instruments was proposed, to which the private sector has been favorable. Additionally, conversations with the northern neighbors (California in the U.S. and Ontario and Québec in Canada) which explore the possibility of a common carbon market has deepened the interest for an ETS. At the moment, SEMARNAT and the CCE are in conversations regarding the design of the ETS; only once they've come to an initial agreement will there be a public consultation.

As of now, no decision has been taken on whether the default carbon-pricing mechanism should be a carbon tax or an ETS. The tax is functioning and collecting revenue, while at the same time Mexico has signed an MOU with California regarding the future linkage of their respective ETS. Ministries have so far taken decisions unilaterally, the Ministry of Finance and Public Credit (SHCP) deciding to introduce a carbon tax and SEMARNAT to introduce an ETS exercise (while the Ministry of Energy had already introduced the CELs). Although there are structures for collaboration, such as the CICC, no clear and unified strategy for climate change mitigation through carbon-pricing exists. There is thus an urgent need for a carbon-pricing debate around the following question: should the default carbon-pricing mechanism be a carbon tax or an ETS? The contribution of this thesis to the debate is presented in Section 6.

5.3.3 COMPARING THE FEASIBILITY OF A CARBON TAX AND AN ETS

As long as their interests are aligned, the public sector will collaborate with academia and NGOs to give solidity to the proposals. The mix of high level of influence of the public sector and the technical support of academia sets the normative conversation. The private (industrial) sector is a more reactive player, and the most determinant one regarding the political feasibility of an instrument.

There is a discrepancy regarding industry preferences between the survey results and the insights obtained through the interview: industry respondents didn't favor clearly any of the proposed instruments, whereas during the interview, it was understood that the position of the CONCAMIN is favorable to an ETS. This discrepancy might be explained by the relatively low level of familiarity with market-based instruments in the circles outside the most influential industrial groups.

Considering this, ETS seems overall the most preferred instrument by both industry and government. Additionally, ear-marking carbon revenue towards climate mitigation program would require revenue to be collected through an ETS, rather than through a tax. However, the importance given by all players to stimulating low-cost investment, might push the decision towards a tax, or to introducing a floor auction price in an ETS. Independently of the selection of the instrument, industry will be very active during the design of the instrument, pushing for either for a low tax rate, for tax exemption on natural gas, or for free allocation of allowances.

[30] Initial years of Felipe Calderón's administration.

6 Conclusions and policy design recommendations

The use of market-based instruments for achieving climate change mitigation goals is gaining traction in the Mexican climate policy arena. Two carbon pricing alternatives exist: carbon tax and ETS, and they both are being explored as valid possibilities by different Federal Ministries. However, no active debate exists as to which of the instruments should regulate the electricity sector. This research aimed to encourage such discussion and assessed both instruments from an economic and from a political feasibility perspectives.

The economic approach allowed to put forward a normative "*first-best*" instrument to maximize economic social welfare, independent of the preferences of the powerful groups involved in the negotiation, or the challenges associated with the institutional and legal contexts. Using scenario-based modeling, and an analysis of international experiences with the instruments, it was established that from the normative economic perspective, a wide-coverage carbon tax with no exemptions, and with revenue-recycling mechanisms, would be the best instrument for reducing emissions from the Mexican power sector. The preliminary suggested value would be a tax gradually increasing to 15 USD/tCO_2; however, although this value has been shown to be appropriate to reduce emissions in the power sector, more research would be required to establish an inter-sectorial nation-wide carbon tax. A mechanism for adjusting the tax rate in light of changing electricity demand projections should be established. Although in many ways comparable, an ETS does not inherently create a stable price signal. Additionally, the regressive behavior of an ETS cannot be easily compensated.

Using the political feasibility approach, the instruments were then assessed as per the preferences and position of different interest groups. Using an on-line survey and in-depth interviews with representatives of the interest groups involved in the Mexican climate policy development (academia, generators, service companies, NGOs, industry and the public sector), it was suggested that an ETS is the most favored instrument. The priority given to low-carbon investment and the importance of ear-marking the carbon revenue to climate change mitigation programs (which in Mexico cannot legally be done with a tax) confirmed such preference. Additionally, the most influential groups in the policy-making process (public sector and industry) favor either exempting natural gas from the tax, or setting it a lower rate. Such exemptions would hinder the performance of a carbon tax, and risk generating a long-term carbon lock-in for the electricity sector. Since an ETS doesn't allow for differentiation regarding fuels, it again emerged as a good "*second best*" alternative for reducing emissions in the power sector. Although an ETS is politically feasible, there are significant challenges in setting the allowance allocation method, as electricity generators and industry favor free allocation, but evidence shows that granting free allowances for the power sector tends to generate windfall profits.

Having answered the research question, recommendations have been developed as to best implement these mechanisms for GHG emissions reduction:

- The most appropriate market-based emission reduction mechanism for the electricity sector is an ETS with the cap set as the conditional target of the INDCs, with auctioned allowance allocation and an auctioning floor-price, as it would generate a stable price signal, allow for the ear-marking of carbon revenue, and avoid exempting natural gas of carbon pricing.
- The initially suggested value for the floor price would be close to the modelled tax of a gradually increasing value, reaching 15 USD/tCO_2 around 2025. It could be set lower to allow for flexibility, for example close to the 13 USD/tCO_2 floor price used in the California CAT, which would also facilitate market linkage.
- The legal status of the floor price should be clearly established to differentiate it from a tax, to avoid future complications such as those which have arisen with the California CAT and the European ETS.
- There is an urgent need for a debate and a trenchant decision regarding the carbon pricing mechanism for emissions reduction, in the electricity sector but also nation-wide. The existing inter-Ministerial coordination group should be utilized to develop a coherent strategy, which may include both an ETS and a carbon tax, each targeting different sectors.

- A balance must be found between the urgency of climate change mitigation and having enough historically accurate emissions data to avoid setting the wrong cap. The threshold for participation in the ETS should be aligned to the threshold for official GHG emissions reporting.
- Given the risk of the newly unbundled CFE subsidiaries holding too much market power, a mechanism similar to the Californian holding limits could be established.
- Based on the priority given to using carbon-revenue for climate mitigation programs, revenue-recycling to poorer households most affected by the electricity tariff raise is unlikely. The regressive characteristic of the ETS remains an unsolved challenge.
- Renewable energy capacity development is extremely sensitive to the discount rate used for the investment assessment. Currently set at 10% by the SHCP, the possibility of reducing it or giving flexibility for energy investment projects should be explored, as this would strongly favor renewables. Were it modified, emission permit demand would decrease, so the ETS cap would need to be adjusted accordingly.

The present work has aimed to be as comprehensive as possible within the available timeframe and resources. However, there are significant limitations which should be noted. The mathematical model used to simulate different carbon-pricing mechanism scenarios was static, while the real situation is dynamic and would require a dynamic modeling framework to be assessed with higher accuracy. Also, being a partial equilibrium model, it did not include the broader economic impacts of the different policies such as job creation. The recommended auctioning floor price is only a preliminary value; further research should be done to select the optimal rate, particularly in the situation where the ETS would incorporate other sectors in addition to the electricity sector. Familiarity with ETS in Mexico is still limited, so the political feasibility assessment of the particular design elements should be taken with caution; a similar assessment should be repeated after the ongoing ETS exercise. The transaction costs associated with establishing a nation-wide ETS and the necessary institutional capabilities were not explored, although they are expected to be significant.

7 References

Andersen, M.S., 2009. Carbon-Energy Taxation, Revenue Recycling and Competitiveness, in: Andersen, M.S., Ekins, P. (Eds.), Carbon-Energy Taxation: Lessons from Europe. Oxford University Press, Oxford ; New York.

Andersen, M.S., 2004. Vikings and virtues: a decade of CO2 taxation. Clim. Policy 4, 13–24. doi:10.1080/14693062.2004.9685507

Andersen, M.S., Barker, T., Christie, E., Ekins, P., Fitz Gerald, J., Jilkova, J., Junankar, S., Landesmann, M., Pollitt, H., Salmons, R., Scott, S., Speck, S., 2007. Competitiveness Effects of Environmental Tax Reforms (COMETR). Final report to the European Commission. National Environmental Research institute, University of Aarhus.

Andersen, M.S., Ekins, P. (Eds.), 2009. Carbon-energy taxation: lessons from Europe. Oxford University Press, Oxford ; New York.

Ares, E., Delebarre, J., 2016. The Carbon Price Floor (Briefing Paper No. Number CBP05927). House of Commons of the UK.

Bailey, E., Borenstein, S., Bushnell, J., Wolak, F.A., 2012. Issue Analysis: Price Containment Reserve in California's Greenhouse Gas Emissions Cap-and-Trade Market.

Banxico, n.d. Serie histórica del tipo de cambio - Pesos por Dólar [WWW Document]. Sist. Inf. Económica. URL http://www.banxico.org.mx/SieInternet/consultarDirectorioInternetAction.do?sector=6&accion=consultarCuadro&idCuadro=CF373&locale=es (accessed 2.16.17).

Baumol, W.J., Oates, W.E., 1988. The theory of environmental policy, 2nd ed. ed. Cambridge University Press, Cambridge [Cambridgeshire] ; New York.

Beck, M., Rivers, N., Wigle, R., Yonezawa, H., 2015. Carbon tax and revenue recycling: Impacts on households in British Columbia. Resour. Energy Econ. 41, 40–69. doi:10.1016/j.reseneeco.2015.04.005

Black, J., Hashimzade, N., Myles, G.D., 2009. A dictionary of economics, 3rd ed. ed, Oxford paperback reference. Oxford University Press, Oxford ; New York.

Borenstein, S., Bushnell, J., Wolak, F.A., 2013. Issue Analysis: Holding Limits in California's Greenhouse Gas Emissions Cap-and-Trade Market.

Borenstein, S., Bushnell, J., Wolak, F.A., Zaragoza-Watkins, M., 2015. Expecting the Unexpected: Emissions Uncertainty and Environmental Market Design (Working Paper No. 20999). National Bureau of Economic Research. doi:10.3386/w20999

Borghesi, S., Montini, M., Barreca, A., 2016. The European emission trading system and its followers: comparative analysis and linking perspectives.

Bosquet, B., 2000. Environmental tax reform: does it work? A survey of the empirical evidence. Ecol. Econ. 34, 19–32. doi:10.1016/S0921-8009(00)00173-7

Bragadóttir, H., von Utfall Danielsson, C., Magnusson, R., Seppänen, S., Stefansdotter, A., Sundén, D., 2014. The Use of Economic Instruments in Nordic Environmental Policy 2010-2013. Nordic Council of Ministers, Copenhagen, Denmark.

Bruvoll, A., Larsen, B.M., 2004. Greenhouse gas emissions in Norway: do carbon taxes work? Energy Policy 32, 493–505. doi:10.1016/S0301-4215(03)00151-4

California Air Resources Board, 2017. California Cap-and-Trade Program Summary of Joint Auction Settlement Prices and Results.

Campos, J., Serebrisky, T., Suárez-Alemán, A., 2016. Tasa de descuento social y evaluación de proyectos: Algunas reflexiones prácticas para América Latina y el Caribe. Inter-American Development Bank. doi:10.18235/0000244

Carl, J., Fedor, D., 2016. Tracking global carbon revenues: A survey of carbon taxes versus cap-and-trade in the real world. Energy Policy 96, 50–77. doi:10.1016/j.enpol.2016.05.023

CENACE, 2017. Mercado y Operaciones [WWW Document]. URL http://www.cenace.gob.mx/MercadoOperacion.aspx (accessed 2.15.17).

Central Intelligence Agency, 2017. The World Factbook: Mexico [WWW Document]. World Factb. — Cent. Intell. Agency. URL https://www.cia.gov/library/publications/the-world-factbook/geos/mx.html (accessed 3.18.17).

Centro Mario Molina, 2014. Análisis de Barreras para la Instrumentación de Tecnologías de Baja Intensidad de Carbono y Propuestas para su Eliminación.

Chuaire, M.F., Scartascini, C., 2014. The Politics of Policies: Revisiting the Quality of Public Policies and Government Capabilities in Latin America and the Caribbean (Policy Brief No. IDB-PB-220). Inter-American Development Bank.

Coase, R.H., 1960. The Problem of Social Cost. J. Law Econ. 3, 1–44. doi:10.1086/674872

Comisión Federal de Electricidad, 2016. Acuerdo de creación de la empresa subsidiaria de la Comisión Federal de Electricidad, DOF 29-03-2016.

Comisión Federal de Electricidad, 2015. Informe Anual 2015.

Cong, R., Lo, A.Y., 2017. Emission trading and carbon market performance in Shenzhen, China. Appl. Energy 193, 414–425. doi:10.1016/j.apenergy.2017.02.037

Congreso de la Unión, 2012. Motivos que sustentan la iniciativa de Decreto por el que se reforman, adicionan y derogan diversas disposiciones de la Ley del Impuesto al Valor Agregado; de la Ley del Impuesto Especial sobre Producción y Servicios y del Código Fiscal de la Federación.

Convery, F.J., 2015. From Theory to Practice - What it Takes to Achieve Implementation of Market-Based Instruments for Environmental Policy, in: Schneider, F., Kollmann, A., Reichl, J. (Eds.), Political Economy and Instruments of Environmental Politics. The MIT Press. doi:10.7551/mitpress/9780262029247.001.0001

Decreto que reforma, adiciona y deroga diversas disposiciones de la Ley del Servicio Público de Energía Eléctrica., 1992. , DOF 23-12-1992.

del Río, P., Labandeira, X., 2009. Barriers to the introduction of market-based instruments in climate policies: an integrated theoretical framework. Environ. Econ. Policy Stud. 10, 41–68. doi:10.1007/BF03353978

Dror, Y., 1969. The Prediction of Political Feasibility. RAND.

Dupont, N., 2017. Balmorel training overview.

Duval, R., 2008. A Taxonomy of Instruments to Reduce Greenhouse Gas Emissions and their Interactions (OECD Economics Department Working Papers No. 636).

Ea Energy Analyses, 2016. Balmorel User Guide.

Ea Energy Analyses, Energinet DK, 2014. EAPP Regional Power System Master Plan.

ECOFYS, Climate Analytics, 2012. Climate Action Tracker: Assessment of Mexico's policies impacting its greenhouse gas emissions profile, Climate Action Tracker Project.

Ellerman, A.D., Marcantonini, C., Zaklan, A., 2016. The European Union Emissions Trading System: Ten Years and Counting. Rev. Environ. Econ. Policy 10, 89–107. doi:10.1093/reep/rev014

Ellerman, D., 2015. The Political Economy of Climate Instruments, in: Schneider, F., Kollmann, A., Reichl, J. (Eds.), Political Economy and Instruments of Environmental Politics. The MIT Press. doi:10.7551/mitpress/9780262029247.001.0001

Energy Innovation, 2017. Carbon Prices Rise In California's Cap-And-Trade Program As Legal Certainty Grows [WWW Document]. Forbes. URL http://www.forbes.com/sites/energyinnovation/2017/02/08/carbon-prices-rise-in-californias-cap-and-trade-program-as-legal-certainty-grows/ (accessed 4.28.17).

Environmental Defense Fund, Natural Resources Defense Council, 2017. California Cap-and-Trade Auction Litigation FAQ.

European Commission, 2017. EU Tax Policy Strategy [WWW Document]. Tax. Cust. Union. URL http://ec.europa.eu/taxation_customs/general-information-taxation/eu-tax-policy-strategy_en (accessed 5.5.17).

European Commission, 2016. EU ETS - Auctioning [WWW Document]. Clim. Action - Eur. Comm. URL https://ec.europa.eu/clima/policies/ets/auctioning_en (accessed 4.4.17).

European Commission, 2014a. COMMISSION REGULATION (EU) No 176/2014 of 25 February 2014 amending Regulation (EU) No 1031/2010 in particular to determine the volumes of greenhouse gas emission allowances to be auctioned in 2013-20.

European Commission, 2014b. Proposal for a DECISION OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL concerning the establishment and operation of a market stability reserve for the Union greenhouse gas emission trading scheme and amending Directive 2003/87/EC.

European Commission Directorate General for the Environment, McKinsey & Company, ECOFYS, 2006. EU ETS Review: Report on International Competitiveness.

European Environment Agency, 2014. Energy support measures and their impact on innovation in the renewable energy sector in Europe [WWW Document]. URL http://www.eea.europa.eu/publications/energy-support-measures (accessed 4.28.17).

European Parliament, 2017. Briefing EU Legislation in Progress: Post-2020 reform of the EU Emissions Trading System.

European Parliament and Council of the European Union, 2009. DIRECTIVE 2009/29/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community, DIRECTIVE 2009/29/EC.

Fabra, N., Reguant, M., 2014. Pass-Through of Emissions Costs in Electricity Markets. Am. Econ. Rev. 104, 2872–2899. doi:10.1257/aer.104.9.2872

Fell, H., 2016. Comparing policies to confront permit over-allocation. J. Environ. Econ. Manag. 80, 53–68. doi:10.1016/j.jeem.2016.01.001

Fullerton, D., 2011. Six Distributional Effects of Environmental Policy (No. w16703). National Bureau of Economic Research, Cambridge, MA. doi:10.3386/w16703

Fullerton, D., 2008. Distributional Effects of Environmental and Energy Policy: An Introduction (No. w14241). National Bureau of Economic Research, Cambridge, MA. doi:10.3386/w14241

Gawel, E., Strunz, S., Lehmann, P., 2014. A public choice view on the climate and energy policy mix in the EU — How do the emissions trading scheme and support for renewable energies interact? Energy Policy 64, 175–182. doi:10.1016/j.enpol.2013.09.008

Gobierno de México, 2015. Compromisos de Mitigación y Adaptación ante el Cambio Climático para el periodo 2020-2030.

Gobierno de México, 2014. Programa Especial de Cambio Climático 2014-2018, DOF 28-04-2014.

González Santaló, J.M., 2009. La generación eléctrica a partir de combustibles fósiles. Bol. IIE 143–151.

Goulder, L.H., Pizer, W.A., 2006. The Economics of Climate Change (Working Paper No. 11923). National Bureau of Economic Research.

Hahn, R.W., Stavins, R.N., 1991. Economic Incentives for Environmental Protection: Integrating Theory and Practice.

Hansjürgens, B. (Ed.), 2005. Emissions trading for climate policy: US and European perspectives. Cambridge University Press, Cambridge ; New York.

Hepburn, C., Neuhoff, K., Acworth, W., Burtraw, D., Jotzo, F., 2016. The economics of the EU ETS market stability reserve. J. Environ. Econ. Manag. 80, 1–5. doi:10.1016/j.jeem.2016.09.010

Hintermann, B., Peterson, S., Rickels, W., 2016. Price and Market Behavior in Phase II of the EU ETS: A Review of the Literature. Rev. Environ. Econ. Policy 10, 108–128. doi:10.1093/reep/rev015

Holt, C.A., Shobe, W.M., 2016. Reprint of: Price and quantity collars for stabilizing emission allowance prices: Laboratory experiments on the EU ETS market stability reserve. J. Environ. Econ. Manag. 80, 69–86. doi:10.1016/j.jeem.2016.01.003

Intergovernmental Panel on Climate Change, 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Geneva, Switzerland.

International Carbon Action Partnership, 2017. Emissions Trading Worldwide Status Report 2017.

International Emissions Trading Association, CDC Climat Research, Environmental Defense Fund, 2015a. United Kingdom, The World's Carbon Markets: A Case Study Guide to Emissions Trading.

International Emissions Trading Association, CDC Climat Research, Environmental Defense Fund, 2015b. California, The World's Carbon Markets: A Case Study Guide to Emissions Trading.

International Energy Agency, 2016. Mexico Energy Outlook.

International Energy Agency, 2005. Lessons from Liberalised Electricity Markets, Energy Market Experience.

International Renewable Energy Agency, 2016. The Power to Change: Solar and Wind Cost Reduction Potential to 2025.

IRENA, 2015. Renewable Energy Policy Brief: Mexico.

Jenkins, J.D., 2014. Political economy constraints on carbon pricing policies: What are the implications for economic efficiency, environmental efficacy, and climate policy design? Energy Policy 69, 467–477. doi:10.1016/j.enpol.2014.02.003

Jones, M.P., 2017. How Much Has the Game Changed? Revisiting Policymaking in Latin America a Decade Later (No. IDB-WP-731), IDB Working Paper Series. Inter-American Development Bank.

Jotzo, F., Löschel, A., 2014. Emissions trading in China: Emerging experiences and international lessons. Energy Policy 75, 3–8. doi:10.1016/j.enpol.2014.09.019

Karplus, V.J., 2011. Climate and Energy Policy for U.S. Passenger Vehicles: A Technology-Rich Economic Modeling and Policy Analysis (PhD). MIT, Cambridge, MA.

Keohane, N.O., Revesz, R.L., Stavins, R.N., 1997. The Positive Political Economy of Instrument Choice in Environmental Policy.

Kirchgässner, G., Schneider, F., 2003. On the Political Economy of Environmental Policy. Public Choice 115, 369–396.

Koch, N., Fuss, S., Grosjean, G., Edenhofer, O., 2014. Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?—New evidence. Energy Policy 73, 676–685. doi:10.1016/j.enpol.2014.06.024

Kolstad, C.D., 2000. Environmental economics. Oxford University Press, New York.

Lehoucq, F., Negretto, G., Aparicio, F., Nacif, B., Benton, A., 2005. Political Institutions, Policymaking Processes, and Policy Outcomes in Mexico (Working Paper No. #R-512), Inter-American Development Bank Research Network. Centro de Investigación y Docencia Económica (CIDE).

Ley de la Industria Eléctrica, 2014. , DOF 11-08-2014.

Ley de Transición Energética, 2015. , DOF 24-12-2015.

Ley del Impuesto Especial sobre Producción y Servicios, 2016. , DOF 15-11-2016.

Ley del Servicio Público de Energía Eléctrica, 1975. , DOF 22-12-1975.

Ley General de Cambio Climático, 2012. , DOF 06-06-2012.

Lin, B., Li, X., 2011. The effect of carbon tax on per capita CO2 emissions. Energy Policy 39, 5137–5146. doi:10.1016/j.enpol.2011.05.050

Martin, R., de Preux, L.B., Wagner, U.J., 2014. The impact of a carbon tax on manufacturing: Evidence from microdata. J. Public Econ. 117, 1–14. doi:10.1016/j.jpubeco.2014.04.016

Martin, R., Muûls, M., Wagner, U.J., 2016. The Impact of the European Union Emissions Trading Scheme on Regulated Firms: What Is the Evidence after Ten Years? Rev. Environ. Econ. Policy 10, 129–148. doi:10.1093/reep/rev016

Mexican Government, 2015. Intended Nationally Determined Contribution - Mexico.

México ya desarrolló un impuesto a las emisiones de carbono; recaudaría mil millones de dólares al año [WWW Document], 2014. . Cámara Diput. H Congr. Unión LXIII Legis. URL http://www5.diputados.gob.mx/index.php/esl/Comunicacion/Boletines/2014/Junio/08/3710-Mexico-ya-desarrollo-un-impuesto-a-las-emisiones-de-carbono-recaudaria-mil-millones-de-dolares-al-ano (accessed 3.9.17).

MexiCO2, 2017. Mexico Cap and Trade Pilot Program.

Morgenstern, R.D., 2005. Design issues of a domestic carbon emissions trading system in the USA, in: Hansjürgens, B. (Ed.), Emissions Trading for Climate Policy: US and European Perspectives. Cambridge University Press, Cambridge ; New York, pp. 114–132.

Munaretto, S., Walz, H., 2015. Political feasibility of climate policy instruments in the EU (Contribution to deliverable 4.5), CECILIA2050 WP4: Policy pathways to a future instrument mix. Institute for Environmental Studies, VU University Amsterdam, Amsterdam.

Munnings, C., Morgenstern, R.D., Wang, Z., Liu, X., 2016. Assessing the design of three carbon trading pilot programs in China. Energy Policy 96, 688–699. doi:10.1016/j.enpol.2016.06.015

Murray, B., Rivers, N., 2015. British Columbia's revenue-neutral carbon tax: A review of the latest "grand experiment" in environmental policy. Energy Policy 86, 674–683. doi:10.1016/j.enpol.2015.08.011

OECD, 2017. Mexico Economic Survey Overview, OECD Economic Surveys.

OECD, 2014. Income inequality. OECD Publishing. doi:10.1787/459aa7f1-en

Padilla, V.R., 2016. Industria Eléctrica en México: Tensión entre el Estado y el mercado. Probl. Desarro. 47, 35–57. doi:10.1016/j.rpd.2015.11.001

Pardo Martínez, C.I., Silveira, S., 2013. Energy efficiency and CO2 emissions in Swedish manufacturing industries. Energy Effic. 6, 117–133. doi:10.1007/s12053-012-9159-5

Raab, U., 2017. Carbon tax - determining the tax rate: Swedish experiences.

Reglamento de la Ley General de Cambio Climático en Materia del Registro Nacional de Emisiones, 2014. , DOF 28-10-2014.

Reinaud, J., 2008. Issues behind competitiveness and carbon leakage: focus on heavy industry. International Energy Agency.

Rogge, K.S., Schneider, M., Hoffmann, V.H., 2011. The innovation impact of the EU Emission Trading System — Findings of company case studies in the German power sector. Ecol. Econ. 70, 513–523. doi:10.1016/j.ecolecon.2010.09.032

Rong, F., 2010. Understanding developing country stances on post-2012 climate change negotiations: Comparative analysis of Brazil, China, India, Mexico, and South Africa. Energy Policy 38, 4582–4591. doi:10.1016/j.enpol.2010.04.014

Rosellón, J., Zenón, E., 2016. Optimal Transmission Planning under the Mexican New Electricity Market.

Russell, C.S., 2001. Applying economics to the environment. Oxford University Press, New York.

Schmalensee, R., Stavins, R., 2015. Lessons Learned from Three Decades of Experience with Cap-and-Trade (Working Paper No. 21742). National Bureau of Economic Research. doi:10.3386/w21742

Secretaría de Hacienda y Crédito Público, 2014. Oficio Circular Tasa Social de Descuento.

SEMARNAT, 2016a. Mexico's Climate Change Mid-Century Strategy.

SEMARNAT, 2016b. Mexico's Policy Update on Carbon Pricing.

SEMARNAT, 2014. Gestión climática en México: Estrategias e instrumentos de mitigación.

SEMARNAT, 2013. Acuerdo por el que se expide la Estrategia Nacional de Cambio Climático, DOF 03-06-2013.

SENER, 2017. Programa de Desarrollo del Sistema Eléctrico Nacional 2017-2031.

SENER, 2016a. Programa de Desarrollo del Sistema Eléctrico Nacional 2016-2030.

SENER, 2016b. Acuerdo de carácter general por el que se determina el concepto de demanda y los requisitos para la agregación de Centros de Carga para ser considerados como Usuarios Calificados, DOF 26-01-2016.

SENER, 2016c. Balance Nacional de Energía 2015. Secretaría de Energía.

SENER, 2015a. Información Estadística [WWW Document]. Sist. Inf. Energética. URL http://sie.energia.gob.mx/bdiController.do?action=temas (accessed 2.17.17).

SENER, 2015b. Acuerdo por el que la Secretaría de Energía emite las Bases del Mercado Eléctrico, DOF 08-09-2015.

SENER, 2015c. Connecting the Americas: Mexico's Electricity Reform.

SENER, 2015d. Acuerdo por el que se emite el Manual de Subastas a Largo Plazo, DOF 19-11-2015.

SHCP, 2016. Acuerdo por el que se actualizan las cuotas que se especifican en materia del impuesto especial sobre producción y servicios., DOF 27-12-2016.

SHCP, 2014. Acuerdo 13/2014 por el que se actualizan las cuotas del Impuesto Especial sobre Producción y Servicios aplicables a los combustibles fósiles, DOF 22-12-2014.

SHCP, 2013. Decreto por el que se reforman, adicionan y derogan diversas disposiciones de la Ley del Impuesto al Valor Agregado; de la Ley del Impuesto Especial sobre Producción y Servicios; de la Ley Federal de Derechos, se expide la Ley del Impuesto sobre la Renta, y se abrogan la Ley del Impuesto Empresarial a Tasa Única, y la Ley del Impuesto a los Depósitos en Efectivo., DOF 11-12-2013.

Sorrell, S., 2003. Back to the Drawing Board? Implications of the EU Emissions Trading Directive for UK Climate Policy. University of Sussex: Science Policy Research Unit.

Speck, S., 1999. Energy and carbon taxes and their distributional implications. Energy Policy 27, 659–667. doi:10.1016/S0301-4215(99)00059-2

Stavins, R.N., 1997. Policy Instruments for Climate Change: How Can National Governments Address a Global Problem?

Swedish Energy Agency, 2016. Energy Indicators in figures 2016 - Follow-up of Sweden´s energy policy goals [WWW Document]. URL http://www.energimyndigheten.se/en/news/2016/energy-indicators-in-figures-2016---follow-up-of-swedens-energy-policy-goals/ (accessed 5.29.17).

Tabla del Inventario Nacional de Emisiones de Gases y Compuestos de Efecto Invernadero 2013, 2013.

Togeby, M., Dupont, N., 2016. Renewable energy scenarios for Mexico. Ea Energy Analyses, Copenhagen, Denmark.

Tracking the Progress of Mexico's Power Sector Reform [WWW Document], 2016. . Wilson Cent. URL https://www.wilsoncenter.org/publication/tracking-the-progress-mexicos-power-sector-reform (accessed 1.5.17).

Transparency International, 2016. Corruption Perceptions Index 2016 [WWW Document]. www.transparency.org. URL https://www.transparency.org/news/feature/corruption_perceptions_index_2016 (accessed 3.16.17).

Tveten, Å.G., Bolkesjø, T.F., 2016. Energy system impacts of the Norwegian-Swedish TGC market. Int. J. Energy Sect. Manag. 10, 69–86. doi:10.1108/IJESM-07-2014-0003

Tveten, Å.G., Bolkesjø, T.F., Ilieva, I., 2016. Increased demand-side flexibility: market effects and impacts on variable renewable energy integration. Int. J. Sustain. Energy Plan. Manag. doi:10.5278/ijsepm.2016.11.4

UNFCCC, 2013. Greenhouse Gas Inventory Data [WWW Document]. United Nation Framew. Conv. Clim. Change. URL http://di.unfccc.int/detailed_data_by_party

United Nations, 2017. World Economic Situation and Prospects 2017. United Nations Pubns, S.l.

United Nations, 2015. Paris Agreement.

US EPA, O., n.d. Greenhouse Gas Equivalencies Calculator [WWW Document]. URL https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator (accessed 2.16.17).

Weishaar, S., 2007. CO2 emission allowance allocation mechanisms, allocative efficiency and the environment: a static and dynamic perspective. Eur. J. Law Econ. 24, 29–70. doi:10.1007/s10657-007-9020-z

Weitzman, M.L., 1974. Prices vs. Quantities. Rev. Econ. Stud. 41, 477–491. doi:10.2307/2296698

Wier, M., Birr-Pedersen, K., Jacobsen, H.K., Klok, J., 2005. Are CO2 taxes regressive? Evidence from the Danish experience. Ecol. Econ. 52, 239–251. doi:10.1016/j.ecolecon.2004.08.005

World Bank, 2017. GDP ranking, PPP based [WWW Document]. World Bank. URL http://data.worldbank.org/data-catalog/GDP-PPP-based-table (accessed 3.15.17).

World Bank Group, 2016. Pricing Carbon [WWW Document]. World Bank. URL http://www.worldbank.org/en/programs/pricing-carbon (accessed 5.26.17).

World Bank Group, ECOFYS, 2016. Carbon Pricing Watch 2016, Carbon Pricing Watch.

World Bank Group, Partnership for Market Readiness, International Carbon Action Partnership, 2016. Emissions Trading in Practice: A Handbook on Design and Implementation.

Worldwide Governance Indicators [WWW Document], 2016. . World Bank. URL http://data.worldbank.org/data-catalog/worldwide-governance-indicators (accessed 3.16.17).

Xiong, L., Shen, B., Qi, S., Price, L., Ye, B., 2017. The allowance mechanism of China's carbon trading pilots: A comparative analysis with schemes in EU and California. Appl. Energy 185, 1849–1859. doi:10.1016/j.apenergy.2016.01.064

Zeng, Y., Weishaar, S.E., Couwenberg, O., 2016. Absolute vs. Intensity-based Caps for Carbon Emissions Target Setting: An Obstacle to Linking the EU ETS to a Chinese National ETS?

Zhao, X., Jiang, G., Nie, D., Chen, H., 2016. How to improve the market efficiency of carbon trading: A perspective of China. Renew. Sustain. Energy Rev. 59, 1229–1245. doi:10.1016/j.rser.2016.01.052

8 Appendix

8.1 Questions to the on-line survey

"This study is conducted as part of a research project at the KTH Royal Institute of Technology in Sweden and Aalto University in Finland. The respondents are the stakeholders involved in or concerned by climate policy in the Mexican electricity sector, i.e. legislators, government officials, electricity generators, industrial electricity consumers, environmental NGOs, and researchers.

The purpose of this survey is to collect data on the preferences regarding climate instruments for the electricity sector, and to identify the factors that affect the political feasibility of an instrument and its design.

It takes about 10 minutes to complete the survey.

Note: This survey is anonymous, unless you specify otherwise."

GENERAL QUESTIONS

To which group of interest do you belong? If you belong to several, chose the one whose interests you represent better:

- Legislator
- Public official
- Industry
- Large-scale electricity producer (>30 MW)
- Small-scale electricity producer (<30 MW)
- Consultancy and other services
- NGO
- Academia

What bests describes the geographical scope of the organization you represent:

- International
- National
- State level
- Municipal

How do you assess the likelihood that Mexico reaches the goals stated in the INDC to reduce greenhouse gas emissions by 25% compared to a BAU scenario?

- (1 to 5) 1: very unlikely, 5: very likely

MARKET-BASED INSTRUMENTS FOR GHG EMISSIONS REDUCTION

Considering the two market-based instruments for greenhouse gas emissions reduction, which one do you think should be the cornerstone of the Mexican climate change mitigation policy?

- Carbon market
- Carbon tax
- Neither (I prefer non-market based instruments such as standard, bans, etc.)

Considering your previous answer, do you strongly prefer or somewhat prefer this policy?

- Strongly prefer
- Somewhat prefer
- Neither, I am close to indifferent

How important are the following criteria for evaluating a climate change mitigation instrument? Order them by level of importance, 1: least important, 6: most important.

- Cost-effectiveness (1 to 6)

- Public costs (1 to 6)
- Addressing uncertainties (1 to 6)
- Distributive equity (1 to 6)
- Stimulates low carbon investment (1 to 6)
- Behavioral change (1 to 6)

Where should the revenue collected by the government through the carbon-pricing instruments be allocated (assume that ear-marking is possible indirectly, by estimating the revenue and then using that value in the Federal expenditure budget) ?

- General budget, as additional revenue (i.e. to reduce budget deficit)
- General budget, to reduce revenue generation from other sources (i.e. reduce income tax)
- It should be ear-marked, and directed towards climate mitigation programs (i.e. renewable energy promotion, investing in public transport, etc.)
- It should be ear-marked, and directed towards helping households affected by higher energy prices
- It should be ear-marked, and directed towards climate change adaptation
- Other (specify: ________________)

To what extent are the following actors influential in shaping the Mexican climate mitigation policies and their ambition? (1 to 5) 1: not influential, 5: very influential

- Legislators
- Public officials
- Industry
- Large-scale electricity generators
- Small-scale electricity generators
- Consulting and other services companies
- NGOs
- Academia

CARBON TAX

Did you know that there is a carbon tax currently in Mexico?

- Yes
- No

The current level of the carbon tax is in the range of 40-50 pesos/tCO_2 for liquid fuels, and around 10 pesos/tCO_2 for coal and coke. Natural gas is excluded from this tax. Would you say the current carbon tax level is:

- (1 to 5) 1: Too low, 5: too high

What do you consider is a correct range of price/ tCO_2 for the carbon tax? (As a reference, the approximate value of the tax in different countries is: Poland <20, Estonia =40, Japan =60, Latvia =80, Portugal =160, France =400, Sweden >1000)

- 0 – 30 pesos/tCO_2
- 30 – 60 pesos/tCO_2
- 60 – 100 pesos/tCO_2
- 100 – 200 pesos/tCO_2
- More than 200 pesos/tCO_2

More than half of electricity generation in Mexico uses natural gas as fuel. Do you think the carbon contents of natural gas should be taxed?

- No
- Yes, at a lower level (pesos/tCO_2) than the other fuels
- Yes, at the same level (pesos/tCO_2) as the other fuels

EMISSION TRADING SYSTEM

Did you know that during 2017 an exercise in emissions trading system will be operating in Mexico?

- Yes
- No

What is your level of familiarity with how a carbon market works?

- (1 to 5) 1: I don't know how it works, 5: I understand perfectly how it works

How do you think the allowances should be allocated to the electricity sector?

- For free based on historical emissions
- For free based on bench-marking
- Through auctioning
- Some for free and some through auctioning

What design characteristics should an ideal Mexican carbon market have?
(1 to 5) 1: very bad idea, 5: very good idea, or I don't know.

- Relative cap
- Absolute cap
- Banking
- Borrowing
- Carbon offsets
- Carbon price floor
- Carbon price ceiling
- Market stability reserve

Here you may add comments regarding your responses to the questions about design characteristics:

OPEN QUESTIONS

Assuming the carbon tax and emissions trading system operated simultaneously, how should they be combined or complemented?

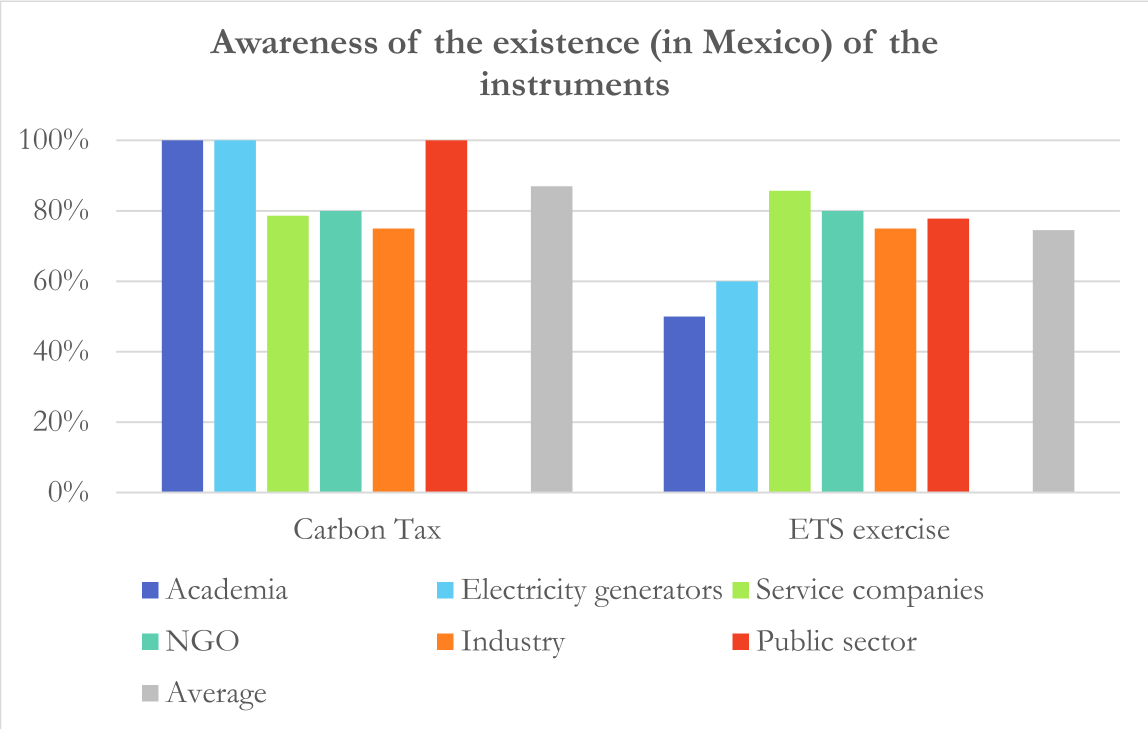
Overall, what would you say is the biggest obstacle to reducing greenhouse gas emissions in the Mexican electricity sector?

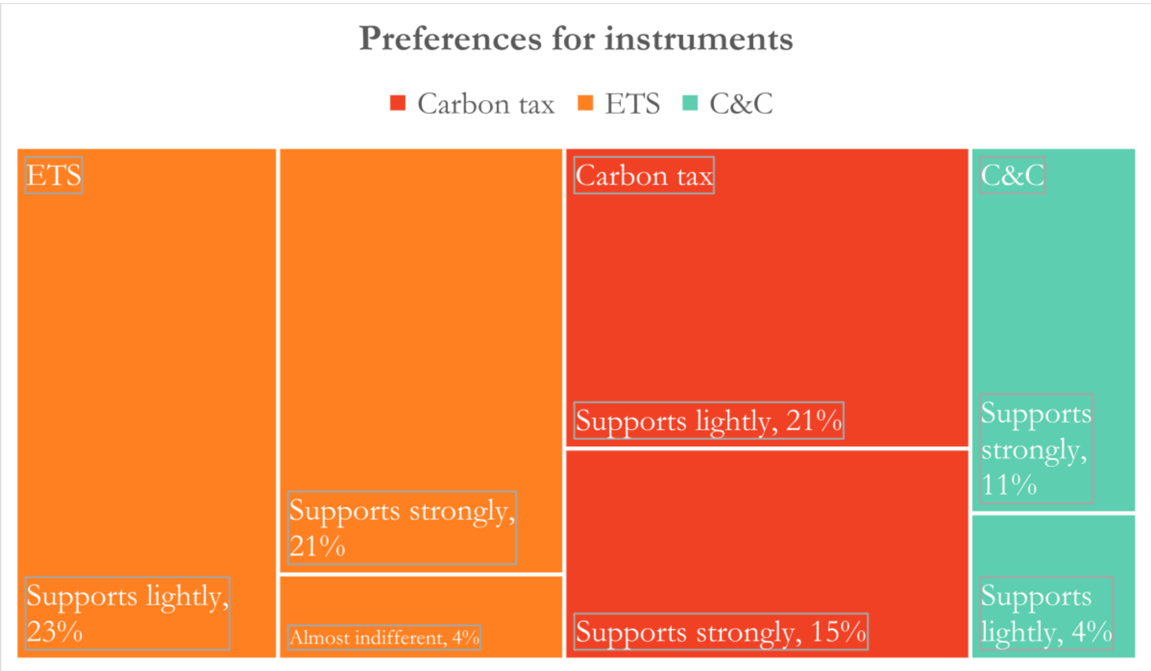
Do you have an additional comment?

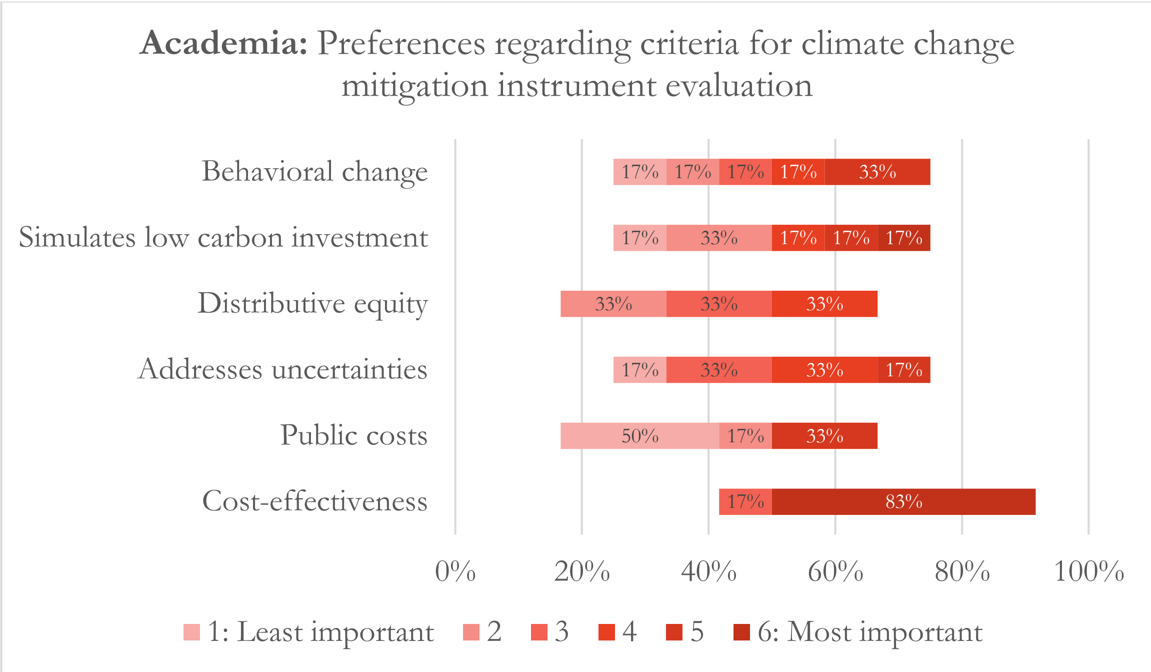
If you have found this survey interesting and would like to see the results, you may leave your email address in the space below, or send an email directly to barraganb.camila@gmail.com.

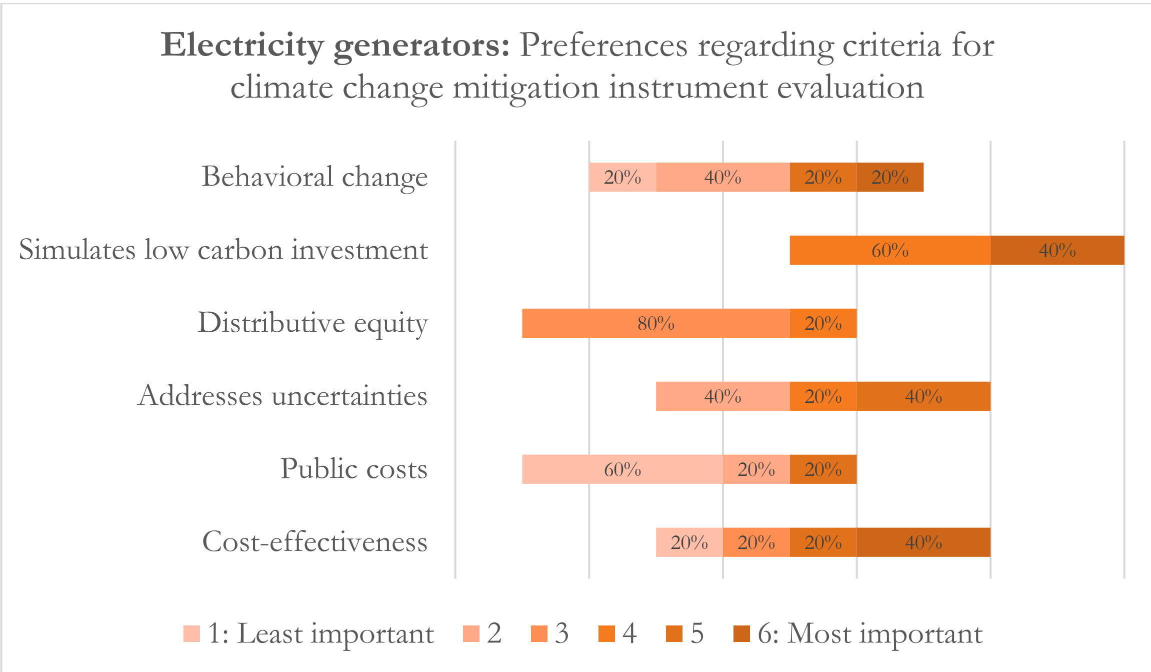
8.2 Answers to the on-line survey

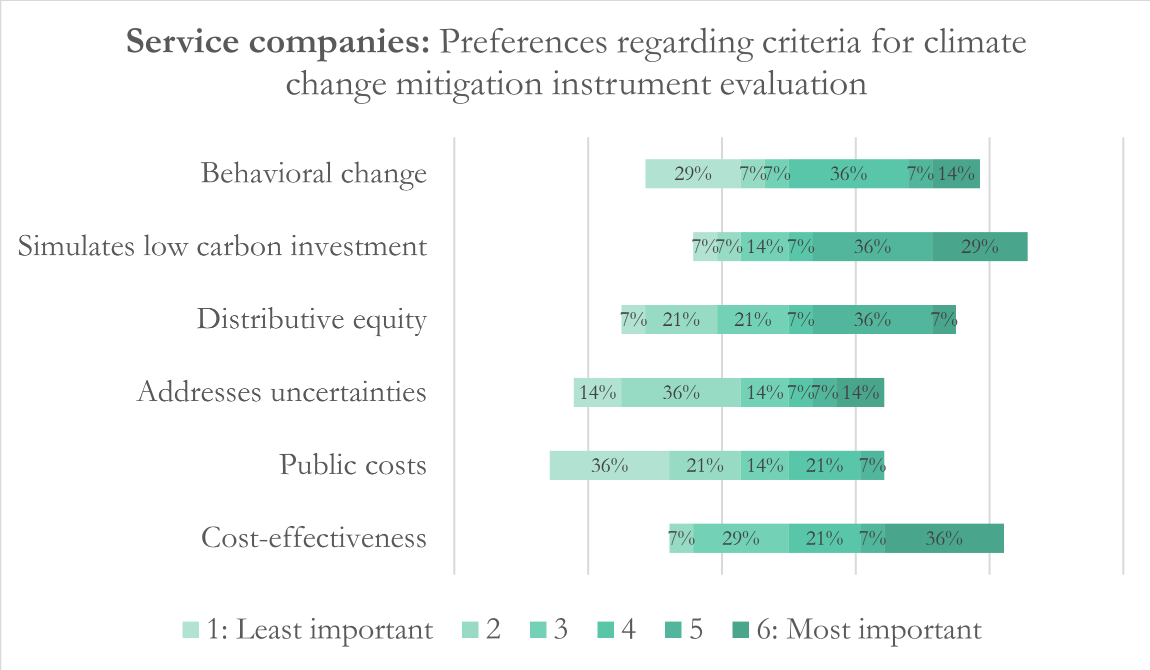
Here are presented the graphs for survey response analysis which are not included in the text.

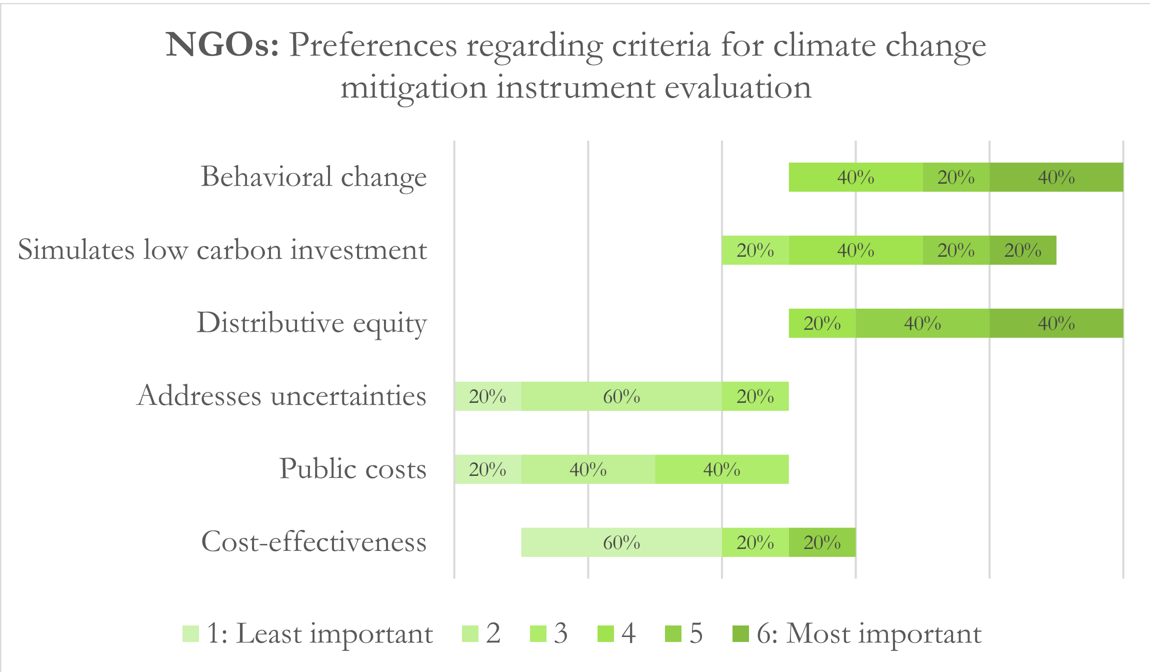


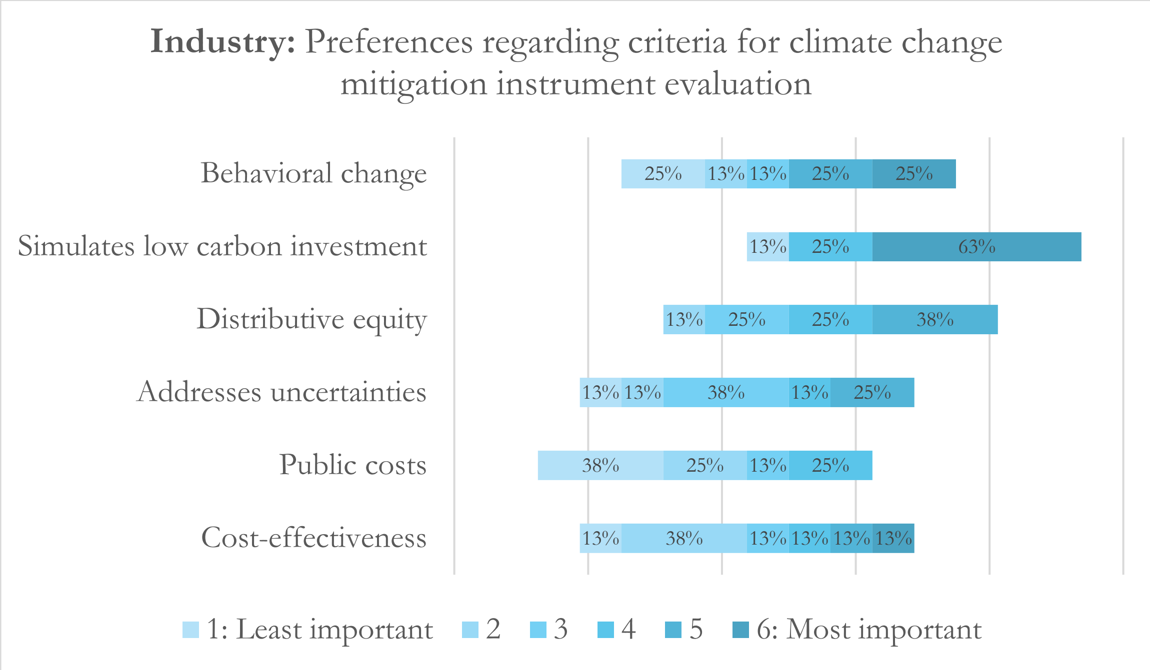


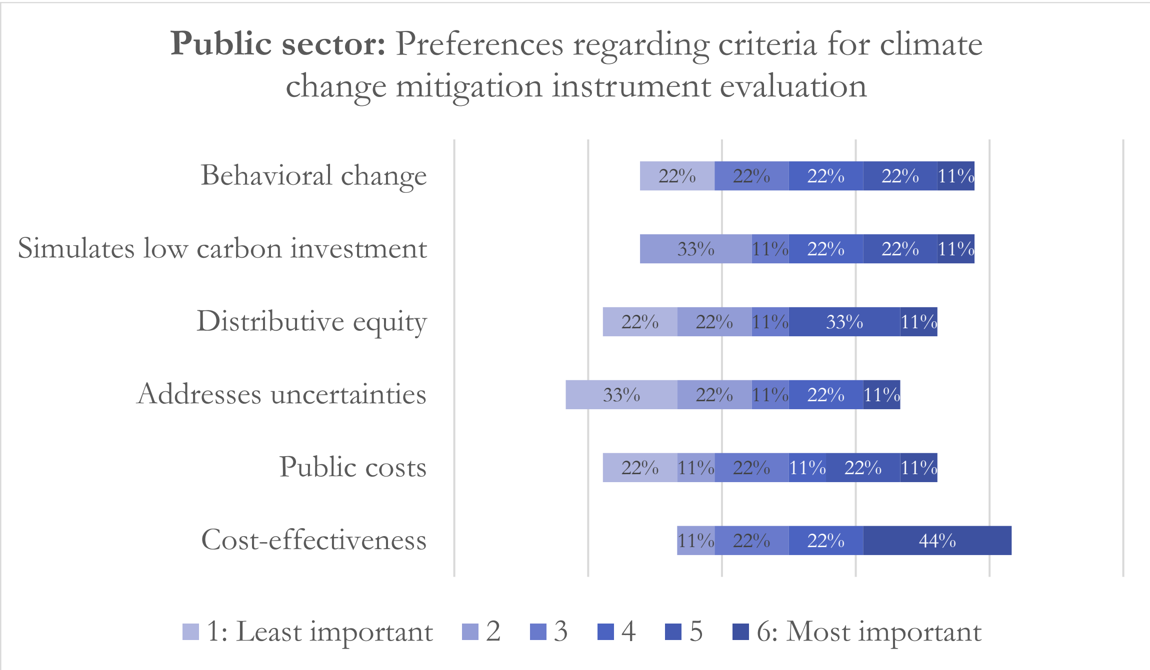

Academia: Preferences regarding criteria for climate change mitigation instrument evaluation
Behavioral change
Simulates low carbon investment
Distributive equity
Addresses uncertainties
Public costs
Cost-effectiveness
17% 17% 17% 17% 33%
17% 33% 17% 17% 17%
33% 33% 33%
17% 33% 33% 17%
50% 17% 33%
17% 83%
0% 20% 40% 60% 80% 100%
1: Least important 2 3 4 5 6: Most important

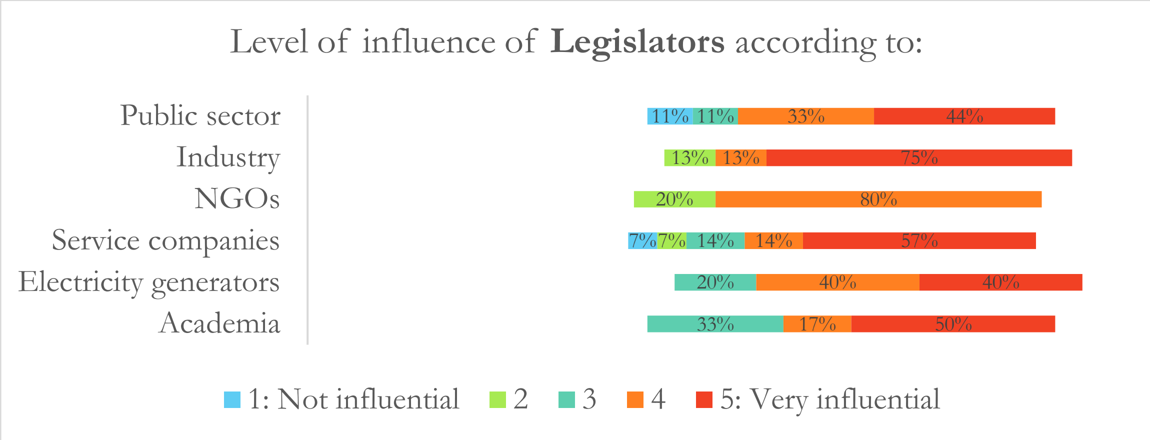

Electricity generators: Preferences regarding criteria for climate change mitigation instrument evaluation
Behavioral change
Simulates low carbon investment
Distributive equity
Addresses uncertainties
Public costs
Cost-effectiveness
20% 40% 20% 20%
60% 40%
80% 20%
40% 20% 40%
60% 20% 20%
20% 20% 20% 40%
1: Least important 2 3 4 5 6: Most important

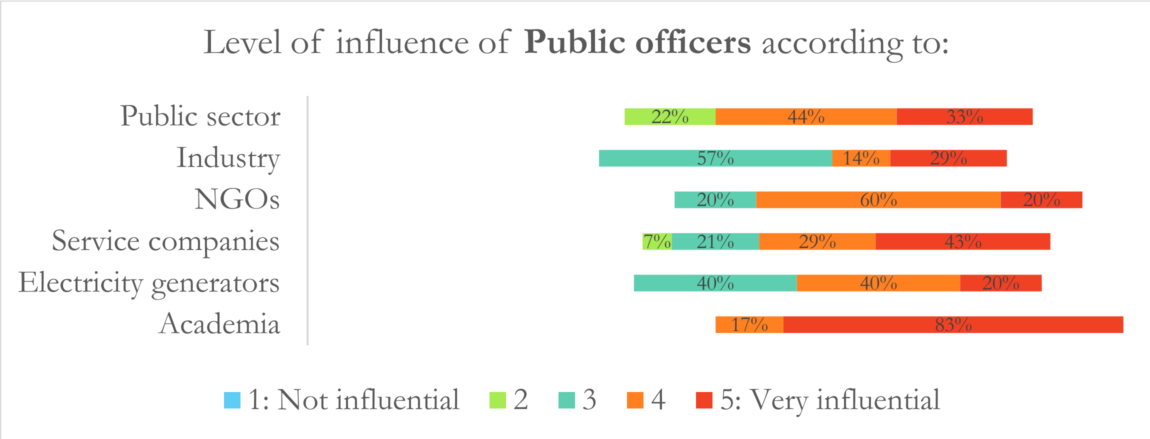

Service companies: Preferences regarding criteria for climate change mitigation instrument evaluation
Behavioral change
29% 7% 7% 36% 7% 14%
Simulates low carbon investment
7% 7% 14% 7% 36% 29%
Distributive equity
7% 21% 21% 7% 36% 7%
Addresses uncertainties
14% 36% 14% 7% 7% 14%
Public costs
36% 21% 14% 21% 7%
Cost-effectiveness
7% 29% 21% 7% 36%
1: Least important
2
3
4
5
6: Most important

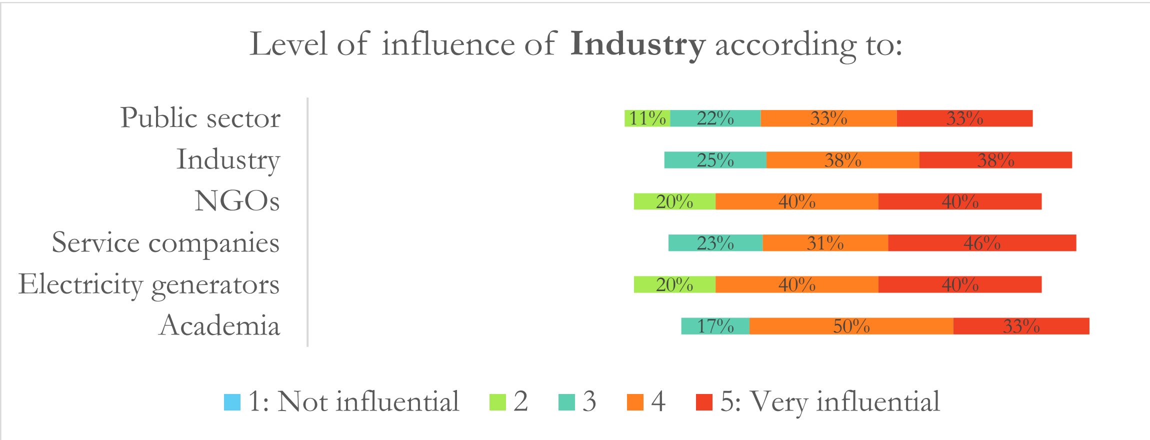

NGOs: Preferences regarding criteria for climate change mitigation instrument evaluation
Behavioral change
40% 20% 40%
Simulates low carbon investment
20% 40% 20% 20%
Distributive equity
20% 40% 40%
Addresses uncertainties
20% 60% 20%
Public costs
20% 40% 40%
Cost-effectiveness
60% 20% 20%
1: Least important
2
3
4
5
6: Most important

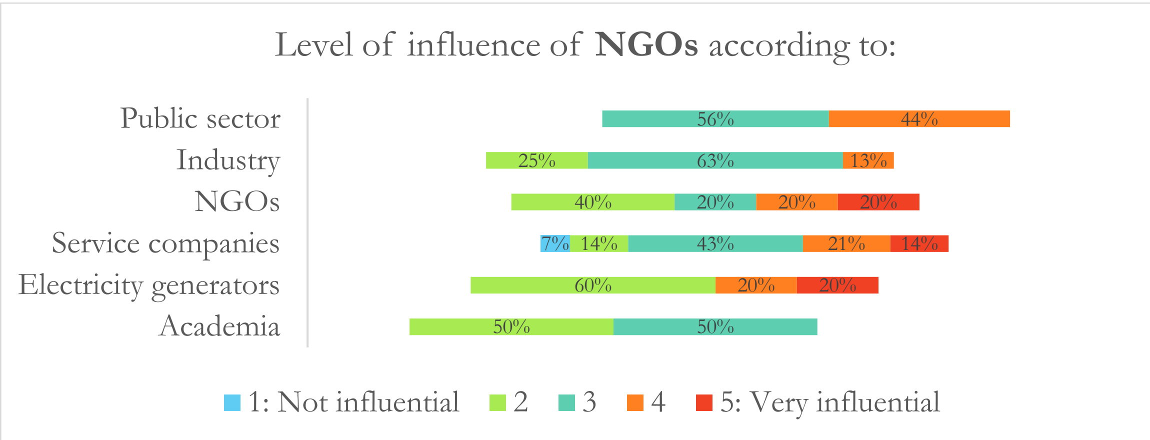

Industry: Preferences regarding criteria for climate change mitigation instrument evaluation
Behavioral change
Simulates low carbon investment
Distributive equity
Addresses uncertainties
Public costs
Cost-effectiveness
25% 13% 13% 25% 25%
13% 25% 63%
13% 25% 25% 38%
13% 13% 38% 13% 25%
38% 25% 13% 25%
13% 38% 13% 13% 13% 13%
1: Least important
2
3
4
5
6: Most important

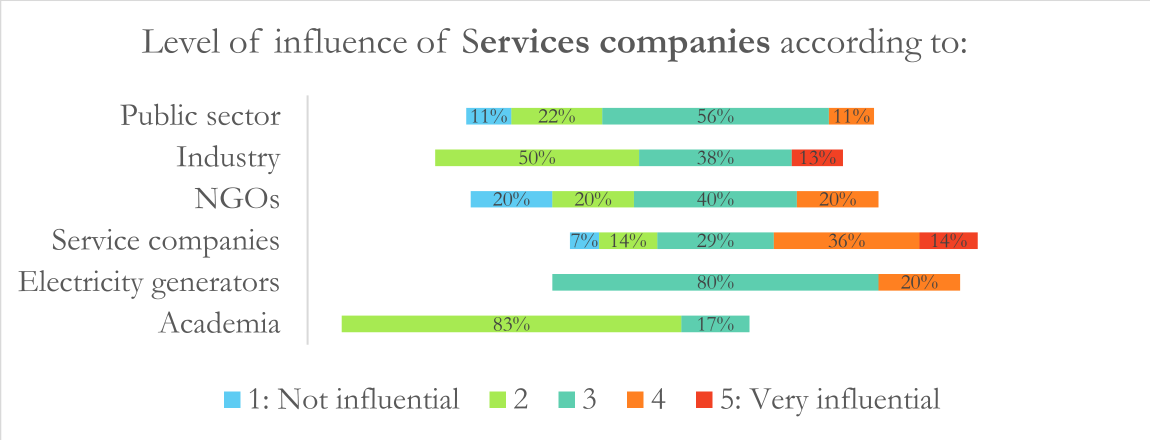

Public sector: Preferences regarding criteria for climate change mitigation instrument evaluation
Behavioral change
Simulates low carbon investment
Distributive equity
Addresses uncertainties
Public costs
Cost-effectiveness
22% 22% 22% 22% 11%
33% 11% 22% 22% 11%
22% 22% 11% 33% 11%
33% 22% 11% 22% 11%
22% 11% 22% 11% 22% 11%
11% 22% 22% 44%
1: Least important
2
3
4
5
6: Most important

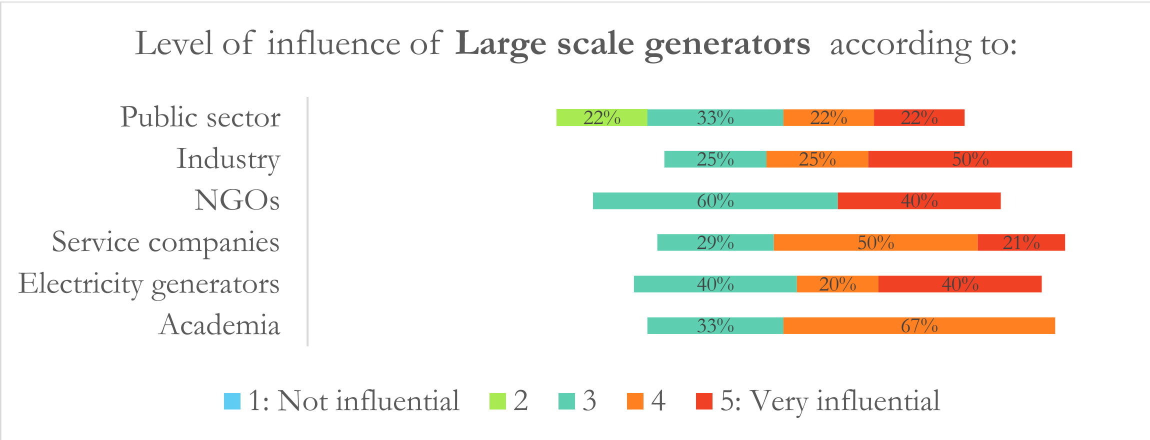

Level of influence of **Legislators** according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
11% 11% 33% 44%
13% 13% 75%
20% 80%
7% 7% 14% 14% 57%
20% 40% 40%
33% 17% 50%
1: Not influential
2
3
4
5: Very influential

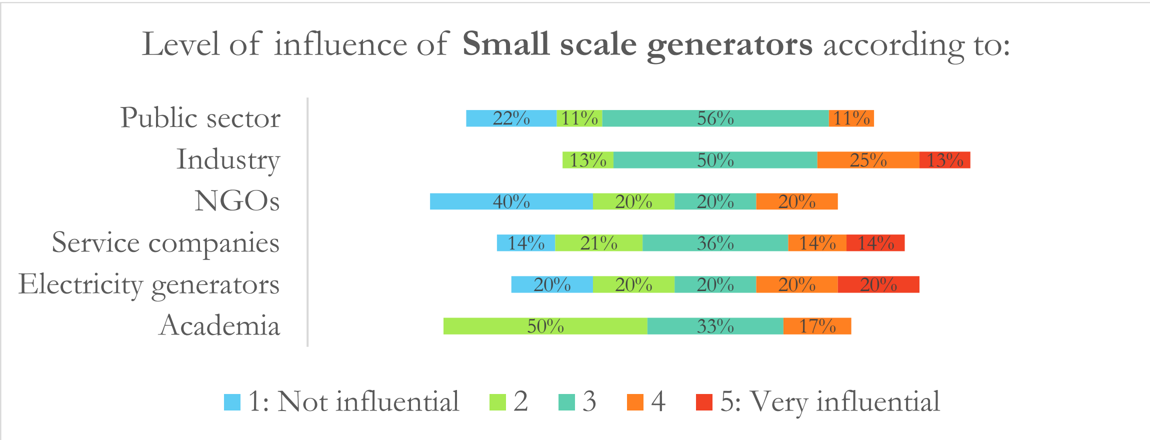

Level of influence of **Public officers** according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
22% 44% 33%
57% 14% 29%
20% 60% 20%
7% 21% 29% 43%
40% 40% 20%
17% 83%
1: Not influential
2
3
4
5: Very influential

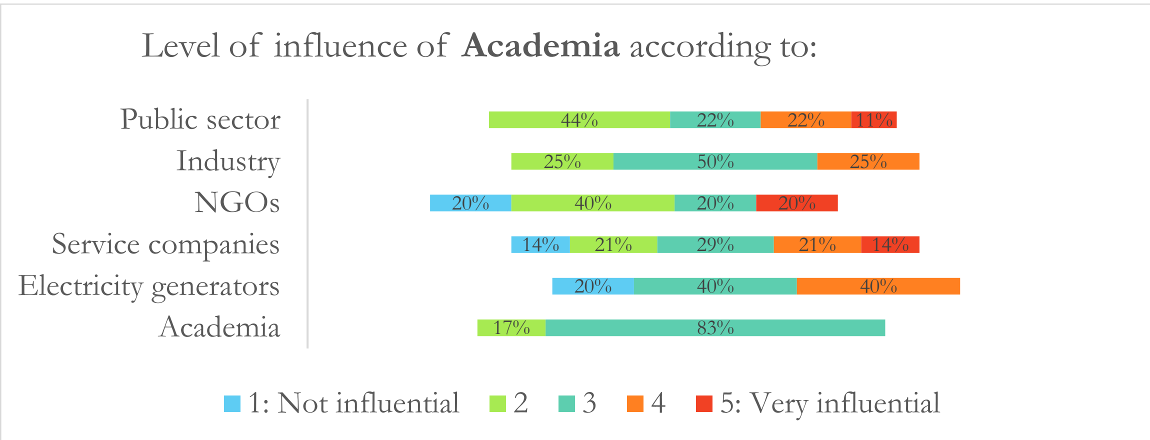

Level of influence of **Industry** according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
11% 22% 33% 33%
25% 38% 38%
20% 40% 40%
23% 31% 46%
20% 40% 40%
17% 50% 33%
1: Not influential
2
3
4
5: Very influential


Level of influence of **NGOs** according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
56% 44%
25% 63% 13%
40% 20% 20% 20%
7% 14% 43% 21% 14%
60% 20% 20%
50% 50%
1: Not influential
2
3
4
5: Very influential


Level of influence of Services companies according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
11% 22% 56% 11%
50% 38% 13%
20% 20% 40% 20%
7% 14% 29% 36% 14%
80% 20%
83% 17%
1: Not influential
2
3
4
5: Very influential


Level of influence of Large scale generators according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
22% 33% 22% 22%
25% 25% 50%
60% 40%
29% 50% 21%
40% 20% 40%
33% 67%
1: Not influential
2
3
4
5: Very influential


Level of influence of Small scale generators according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
22% 11% 56% 11%
13% 50% 25% 13%
40% 20% 20% 20%
14% 21% 36% 14% 14%
20% 20% 20% 20% 20%
50% 33% 17%
1: Not influential
2
3
4
5: Very influential


Level of influence of Academia according to:
Public sector
Industry
NGOs
Service companies
Electricity generators
Academia
44% 22% 22% 11%
25% 50% 25%
20% 40% 20% 20%
14% 21% 29% 21% 14%
20% 40% 40%
17% 83%
1: Not influential
2
3
4
5: Very influential

OPEN QUESTIONS

What are the obstacles for reducing GHG emissions in the Mexican electricity sector?

Academia	Investments and support for **Natural gas** Political promises to reduce electricity tariffs has gone **in front of cc mitigation policy** Requires **efficient functioning of the electricity and CELs market**
Elec. gen.	**Opposition** from the industry who says that any additional costs such as tax or buying permits will affect their competitiveness Ignorance of **consumers**
Consulting and other services	"**Slow deregulation of the electricity sector** Financial barriers are decreasing, but **infrastructure barries (transmission)** remain **Institutional capacity of the governmental** institutions involved Reducing GHG emissions from power sector is **not the priority** **Natural gas** is still the most reliable energy source **Opposition** from industrial large consumers
NGOs	The idea that **Natural gas** is clean – it causes carbon lock-in **Low cost of fossil fuels**, which don't include the externality **Opposition** from affected parties
Industry	Old technology, **Low investment**, **Consumer** behavior (The lack of) availability of **Natural gas**, which can substitute more polluting fuels **Low ability of the government** to execute projects in general
Public sector	Exclusive bet on **Natural gas**, thinking of it as a long-term fuel instead of a transition fuel **Opposition** by carbon 'producers' and their influence in Congress **Lack of investment** in diversifying energy mix Insufficient **transmission infrastructure** **Fossil fuel subsidies** Lack of understanding of how ETS works

How should the carbon tax and the ETS be combined?

No co-existance	"They should not exist in parallel " "Carbon tax should be eliminated" "ETS alone is enough (for the electricity sector)" "Implementation should be sequential" "They should not be combined"
Complementary	"Can be complemented" "Carbon tax should be the floor price for ETS" "Allowance permits can be used to deduce from tax obligations" "Every Company should pay a tax, but the more efficient ones can be rewarded by selling their additional reductions to less efficient companies" "If carbon tax is maintained, then allowances should be given for free. While NG is not taxed and coal has a reduced tax, allowances should be auctioned. "A share of the carbon tax revenue could be used as MSR for the ETS" "Carbon tax could be deduced if firms have investments in RE, EE" "They should work as independent mechanisms" "They should be added up" "They should be combined optimally" "Tax should be used to pay for the losses and damages of CC; ETS should be used as an additional incentive to improve sustainablity of productive sectors"
Target different sectors	"Carbon tax should be applied to all sectors which do not participate in ETS" "ETS in industrial and electricity sector, carbon tax for transport" "ETS can be used for sectorial targets, while the carbon tax can be used for fuels" "They should not target the same sectors" "Use tax for sectors not covered in the ETS"
Target different fuels	"Carbon tax should only be levied on the most pollution fuels (coal, coke, fuel oil), the rest should be left to a flexible market"

General comments:

Academia	The non-conditional targets (to the INDC) do NOT represent a technological/economic challenge; discussion should be centered around the conditional targets
Elec. gen.	-
Consulting and other services	There is a need to **align the strategies of SENER (Ministry of Energy) and SEMARNAT (Ministry of Environment and Natural Resources)** Emission permits and Green certificates (CELs) should be "homologated" For ETS: Banking is important to give certainty, **floor and ceiling price** should be established Intermittent renewables should be charged for the cost of electricity storage, so they can compete on equal grounds with **base-load renewables such as geothermal** Good survey, but in Mexico the "informed universe" is still too small – this survey should be repeated regularly, to see the changes in response
NGOs	-
Industry	If co-existing, both instruments should be **regulated by the same entity**, with the same objective, to avoid overlapping
Public sector	**Geothermal and hydro technologies** should be "made competitive" through auctions or other mechanisms All fiscal income must go to general budget – the area of opportunity lies in the revenue from ETS, which could be directed to mitigation actions. While the market stabilizes, it is important to **set price collars** to avoid very low or high prices (initially) A **cross-cutting agreement** is necessary, if both instruments are to co-ex since the instruments are the responsibility of **different Ministries**

8.3 Guiding questions for the interviews

"The objective of this interview is to understand the role of the different interest groups This study is conducted as part of a research project at the KTH Royal Institute of Technology in Sweden and Aalto University in Finland. The respondents are the stakeholders involved in or concerned by climate policy in the Mexican electricity sector, i.e. legislators, government officials, electricity generators, industrial electricity consumers, environmental NGOs, and researchers.

Do you consider that there is currently a debate about climate change mitigation policy in Mexico?

- If so, which actors are participating most actively?
- In which setting is this debate taking place?

Could you give me an example of a policy proposal which would you advance, which would not be accepted because of opposition from other groups?

What is the role of the media in this debate? Which actors have influence in what the media portrays?

Which factors do you consider had a role in the introduction of market-based instruments in the Mexican climate policy?

- Which groups have supported this, and which have opposed it? Which of these groups has the most influence?

In general, what is the role of your institution in shaping the Mexican climate policy?

- How do you advance your positions? With whom do you collaborate?

Do you have a success (or failure) story regarding your involvement with climate policy development?

How could the upcoming elections (in 2018) affect the development of instruments for GHG emission reduction?

- Is there institutional or legal 'robustness' which would permit the continuity of such instruments?

Is there any other aspect of the climate policy development which we have not touched upon yet and which you think is important to mention?"

8.4 List of interviewees

- Dr. Lourdes Melgar, Researcher at MIT, former Subsecretary of Electricity and Hydrocarbons
- Dr. Gerardo Mejía, Researcher at Tecnológico de Monterrey
- Business Developer at Enel Green Power México
- Energy Manager at a steel manufacturing company
- Julia Martinez, Climate and Energy Senior Fellow at World Resources Institute Mexico
- Saúl Pereyra, Deputy Director for Climate Change Mitigation, Ministry of Natural Resources (SEMARNAT)
- Jessica Rodríguez, Director for Renewable Energies, Ministry of Energy (SENER)
- Andrés Prieto, Research Analyst at MexiCO2